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THE FATIGUE STRENGTH OF VARIOUS TYPES OF BUTT WELDS CONNECTING STEEL PLATES

A REPORT OF AN INVESTIGATION

CONDUCTED BY

THE ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

IN COOPERATION WITH

THE PUBLIC ROADS ADMINISTRATION,
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I. Introduction

1. *Object and Scope of Investigation*

In the fabrication of steel structures, butt welds are used to connect steel plates under a variety of conditions. The tests reported in this bulletin were planned to determine the fatigue strength of several types of butt welds under conditions similar to those encountered in practice. One condition studied is that of a joint in a thick plate under loads that produce a relatively low stress in the joint. The girth seam of a cylindrical pressure vessel is a well known and frequent example. The question has been raised whether a partial-penetration weld[1] might not be used under these conditions, with a considerable reduction in the cost of welding and without a reduction in safety even under conditions conducive to fatigue failure. As an answer to this question a considerable part of this bulletin consists of the results of fatigue tests of partial-penetration butt welds connecting ⅞-in. A7 steel plates. Both longitudinal and transverse partial-penetration welds were tested. Some were tested in the as-welded condition; for others, the reinforcement was machined off. Specimens with the reinforcement on were tested at room temperature, and at −20 deg F.

The object of a second group of tests was to determine the fatigue strength of 4 series of specimens each of which consisted of a ½-in. A7 steel plate connected by single-V transverse butt welds from which the reinforcement had been removed. The specimens of two series were welded with E6010 electrodes; of the other two, with E6012 electrodes. For each group of two series, the specimens of one series were tested without being stress-relieved; for the second series they were stress-relieved by a high-temperature method.

A third group of tests consisted of eight series of tests for which the specimens were ½-in. plates connected with longitudinal single-V butt welds. The specimens of four of these series were tested with the reinforcement on; for the other four series the reinforcement was machined off. For each group of four series, the specimens of one series were tested without being stress-relieved; for the other three series of each group, the specimens for one series were stress-relieved by a high-temperature method, for a second series they were stress-relieved by a low-temperature method, for the third series they were stress-relieved by a mechanical method. All these tests

[1] The term "partial-penetration weld" is used throughout this bulletin to indicate groove welds which have a total depth of groove less than the thickness of the piece. See Fig. 3, p. 17.

of single-V butt-weld specimens were made at room temperature (approximately 75 deg F).

All these above series of tests are described in Table 1.

2. *Acknowledgments*

The tests described in this bulletin were a part of the investigation resulting from a cooperative agreement entered into by the Engineering Experiment Station of the University of Illinois, of which Dean M. L. Enger was then the Director, and the Public Roads Administration, Federal Works Agency, of which Thomas H. MacDonald is the Commissioner. The tests were planned in cooperation with the Committee on Fatigue Testing (Structural), Welding Research Council of the Engineering Foundation, of which F. H. Frankland was then Chairman, and financed by the Chicago Bridge and Iron Company; the Public Roads Administration, Federal Works Agency; the Bureau of Ships, Navy Department; the American Iron and Steel Institute; and the Association of American Railroads. They were made in the Arthur Newell Talbot Laboratory by William H. Munse, Special Research Assistant Professor of Civil Engineering, and I. S. Snyder, Special Research Assistant in Civil Engineering, working under the supervision of W. M. Wilson, Research Professor of Structural Engineering.

The tests were planned by a Sub-Committee of the Committee on Fatigue Testing (Structural) of which H. C. Boardman is Chairman.

The partial-penetration specimens used in this investigation were contributed by the Chicago Bridge and Iron Company. The steel for the ½-in. specimens was contributed by the Bethlehem Steel Co. The specimens that were stress-relieved by the low-temperature method were stress-relieved by the Linde Air Products Company.

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TABLE 1
DESCRIPTION OF SPECIMENS FOR ALL SERIES*

Factor Being Studied	Series No.	Nominal Penetration, in.	Direction of Weld	Reinforcement	Stress-Relieved	Temperature When Tested, deg F
Butt Welds in ⅞-in. A7 Steel Plate; Electrode E6010; Not Stress-Relieved						
Partial Penetration	A-I	¼	Long.	On	No	Room
	A-II	3/16	Long.	On	No	Room
	A-III	¼	Long.	On	No	−20
	B-I	¼	Trans.	On	No	Room
	B-II	5/16	Trans.	On	No	Room
	B-III	¼	Trans.	On	No	−20
	D-I	¼	Long.	Off	No	Room
	D-II	¼	Trans.	Off	No	Room
	D-III	3/16	Long.	Off	No	Room
	D-IV	3/16	Trans.	Off	No	Room
	P-I		No Weld		No	Room
Single-V Butt Welds in ½-in. A7 Steel Plate; Electrode E6012 for Series H-I and H-II; Electrode E6010 for all others						
Kind of Electrode	F-I		Trans.	Off	No	Room
	F-III		Trans.	Off	Yes‡	Room
	H-I		Trans.	Off	No	Room
	H-II		Trans.	Off	Yes‡	Room
	F-V		No Weld		No	Room
Single-V Butt Weld in ½-in. A7 Steel Plate; Electrode E6010						
Stress-Relieving†	G-I		Long.	On	No	Room
	G-II		Long.	On	Yes‡	Room
	G-IV		Long.	Off	No	Room
	G-V		Long.	Off	Yes‡	Room
	G-III		Long.	On	Yes¶	Room
	G-VI		Long.	Off	Yes¶	Room
	H-III		Long.	On	Yes§	Room
	H-IV		Long.	Off	Yes§	Room

* The results of these tests are summarized in Tables 11, 21, and 33.
† The various methods of stress-relieving are described on pp. 45–46.
‡ High-temperature method.
¶ Mechanical method.
§ Low-temperature method.

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3. *Description of Tests*

The fatigue tests described in this bulletin were planned to determine the fatigue strength of the specimens when tested on a cycle in which the stress varied from 0 to a maximum tension. Some tests were planned to give the fatigue strength corresponding to failure at 100,000 cycles, designated as $F_{100\,000}$; other tests were planned to give the fatigue strength corresponding to failure at 2,000,000 cycles, designated as $F_{2\,000\,000}$.

The values of $F_{100\,000}$ and $F_{2\,000\,000}$ were computed from the results of the tests by means of the empirical equation[1] $F_n = S\,(N/n)^K$, in which S, numerically, is the maximum stress in the stress cycle, N is the number of cycles for failure for the test in question, K is an experimental constant whose value depends upon such factors as the geometrical characteristics of the specimen and the mechanical properties of the metal, and F_n is the fatigue strength corresponding to failure at n number of cycles. The value of K for each series was determined from the slope of the S-N (stress–number of cycles for failure) diagram for the series in question, and has different values for different types of specimens. The error in F_n resulting from the use of an inaccurate value of K depends upon the amount by which the ratio N/n differs from unity. The following arbitrary rule was followed in deciding whether the results of a particular test were to be used to determine $F_{100\,000}$ or $F_{2\,000\,000}$. Values of $F_{100\,000}$ were determined from tests for which n was less than 600,000; values of $F_{2\,000\,000}$ were determined from tests for which n was greater than 300,000; and values of both $F_{100\,000}$ and $F_{2\,000\,000}$ were determined from tests for which n was more than 300,000 and less than 600,000. If the number of cycles for failure exceeded 2,000,000, the value of the maximum stress in the stress cycle was reported as the value of $F_{2\,000\,000}$. This value is followed by a plus sign (+), indicating that the actual value is somewhat greater than the value reported.

The chemical composition of the plates as determined by mill

[1] See Univ. of Ill. Eng. Exp. Sta. Bul. 302, p. 111.

tests is given in Table 2 for each of the parent plates. The location in the parent plate of each fatigue specimen and each control specimen is shown in Figs. 1 and 2. The mechanical properties of the parent plates as determined by static tests of the standard control specimens are given in Table 3. The welding procedures for the welds of the various series are given in Tables 4 and 5. Table 4 presents the procedure for the partial-penetration butt welds; Table 5 presents the procedure used for the single-V butt welds of Series F, G, and H.

The E6010 and E6012 electrodes used for Series F, G, and H are in common use for general structural welding; hence they have

Table 2
Chemical Composition of All Plates as Given by Mill Reports

Plate	Series	Thickness, in.	Chemical Composition, percent			
			C	Mn	P	S
A, B, C	A, B, P	⅜	0.20	0.55	0.018	0.028
D	D	⅜	0.25	0.53	0.018	0.038
F, G, H	F, G, H	½	0.21	0.48	0.013	0.037

been compared in this program. Both types are considered as "All-Position" electrodes. Electrodes of the E6010 class are used on reversed polarity, direct current only, and produce a deep penetrating weld. The E6012 type electrode is used on either alternating current or straight polarity, direct current, and produces a weld of medium penetration.

Static tests were also made on fatigue-type specimens — that is, specimens identical with the specimens used in the fatigue tests. The results of these static tests are reported with the results of the fatigue tests.

A description of the various types of specimens and the results of the tests are given in the following sections.

All plates were of ASTM A7 carbon steel. All tests were on a cycle: 0 to tension. Unless otherwise specified, all tests were at room temperature (approximately 75 deg F) and the specimens were tested in the as-welded condition (reinforcement on, not stress-relieved).

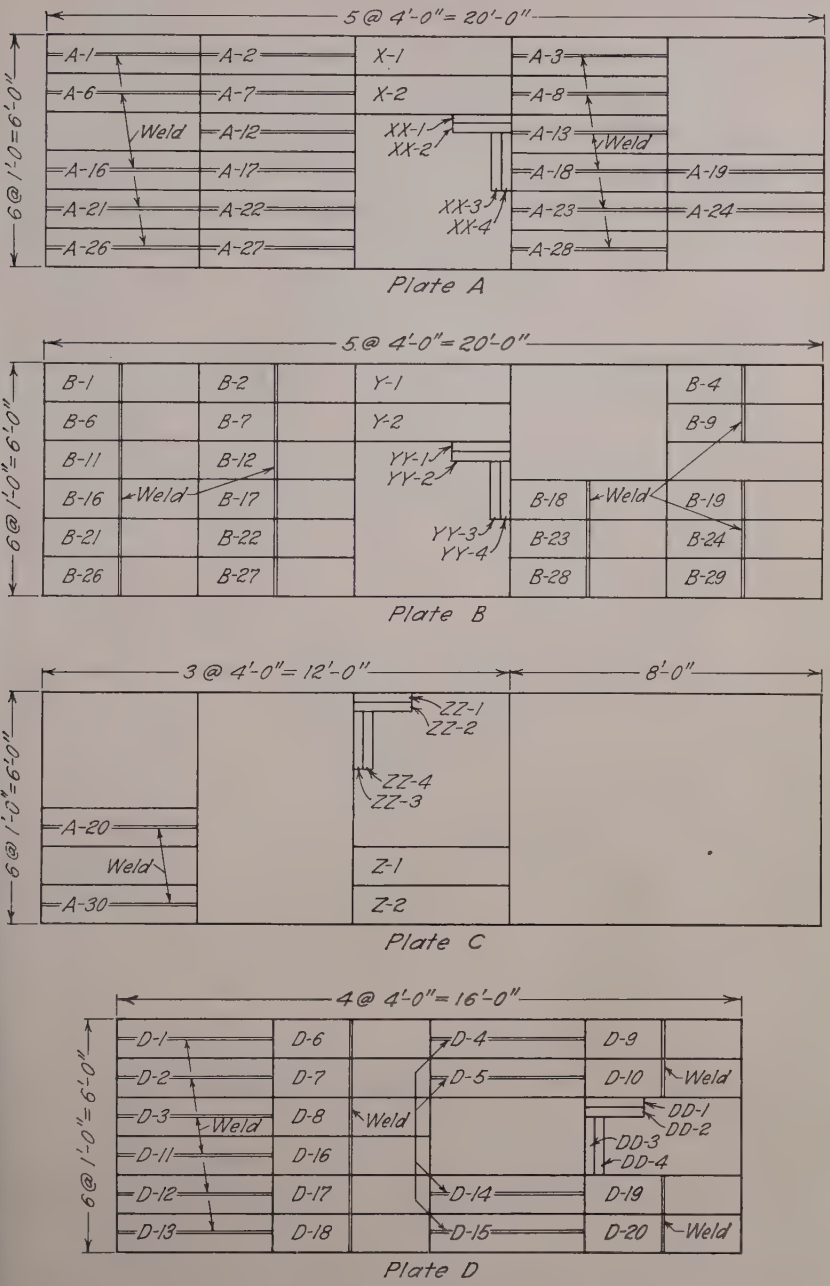


FIG. 1. LOCATION OF SPECIMENS IN PARENT PLATES: PLATES 7/8 IN. THICK

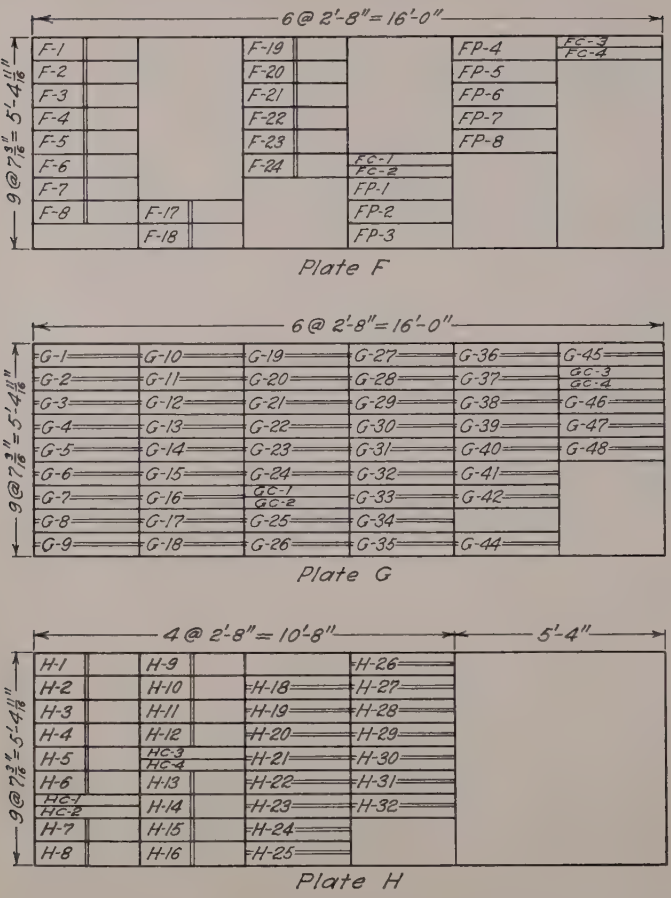


FIG. 2. LOCATION OF SPECIMENS IN PARENT PLATES: PLATES ½ IN. THICK

TABLE 3

MECHANICAL PROPERTIES OF THE STEEL PLATES FOR ALL SERIES

(Laboratory Coupon Tests)

Coupon Specimen No.	Parent Plate	Strength in p.s.i.		Elongation in 8 in., percent	Reduction of Area, percent
		Yield Point	Ultimate		
XX-1	A	34 600	62 000	35	56
XX-2	A	35 700	61 900	32	56
XX-3	A	35 600	61 600	30	51
XX-4	A	35 200	61 800	30	51
Av		35 300	61 800	32	53
YY-1	B	36 800	61 900	33	57
YY-2	B	36 000	61 100	34	59
YY-3	B	37 100	60 700	32	51
YY-4	B	35 400	61 000	33	52
Av		36 300	61 200	33	55
ZZ-1	C	35 600	59 900	33	58
ZZ-2	C	35 300	58 300	36	53
ZZ-3	C	36 100	60 500	28	47
ZZ-4	C	36 000	61 000	29	49
Av		35 800	59 900	32	52
DD-1	D	34 800	65 900	31	49
DD-2	D	35 000	65 800	29	51
DD-3	D	34 500	66 000	29	35
DD-4	D	35 100	66 100	26	34
Av		34 900	65 900	29	42
FC-1	F	36 700	59 200	30	50
FC-2	F	35 800	59 100	31	51
FC-3	F	37 700	59 200	32	55
FC-4	F	36 600	60 900	30	52
Av		36 700	59 600	31	52
GC-1	G	35 500	58 600	33	55
GC-2	G	37 500	58 500	32	50
GC-3	G	35 500	59 700	30	56
GC-4	G	35 900	59 700	31	54
Av		36 100	59 100	32	54
HC-1	H	36 000	58 000	31	52
HC-2	H	35 200	57 900	31	54
HC-3	H	35 800	58 000	30	53
HC-4	H	35 200	58 100	33	53
Av		35 550	58 000	31	53

TABLE 4
WELDING PROCEDURES FOR PARTIAL-PENETRATION BUTT WELDS

Weld Pass*	Weld Rod and Size	Welding Range		Electrode	Position
		Amps	Volts		
	(a) ¼-in. Partial-Penetration Welds				
1	3/16″ φ E6010	150-175	38	Positive	Flat
2	3/16″ φ E6010	150-175	38	Positive	Flat
3	3/16″ φ E6010	150-175	38	Positive	Flat
4	3/16″ φ E6010	150-175	38	Positive	Flat
	(b) 3/16-in. Partial-Penetration Welds				
1	5/32″ φ E6010	125-150	28	Positive	Flat
2	5/32″ φ E6010	125-150	28	Positive	Flat
3	3/16″ φ E6010	150-175	38	Positive	Flat
4	3/16″ φ E6010	150-175	38	Positive	Flat

* See Figs. 3 and 4.

TABLE 5
WELDING PROCEDURES FOR SINGLE-V BUTT WELDS

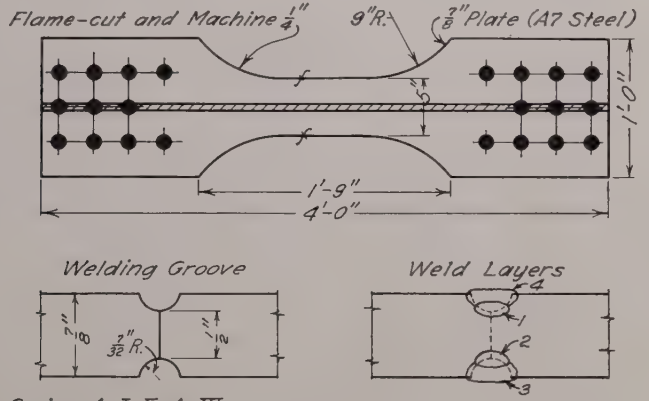
Weld Pass	Weld Rod and Size	Welding Range		Electrode	Position
		Amps	Volts		
	(a) Procedure for All "F" Series				
1*	5/32″ φ E6010	120	24	Positive	Flat
2*	3/16″ φ E6010	190	27	Positive	Flat
3*	3/16″ φ E6010	190	27	Positive	Flat
4*	3/16″ φ E6010	205	28	Positive	Flat
5*	3/16″ φ E6010	205	28	Positive	Flat
	(b) Procedure for All "G" Series, H-III and H-IV				
1†	5/32″ φ E6010	160	Normal	Positive	Flat
2†	3/16″ φ E6010	200	Normal	Positive	Flat
3†	3/16″ φ E6010	200	Normal	Positive	Flat
4†	3/16″ φ E6010	220	Normal	Positive	Flat
5†	3/16″ φ E6010	220	Normal	Positive	Flat
	(c) Procedure for Series H-I and H-II				
1‡	5/32″ φ E6012	130	Normal	Negative	Flat
2‡	3/16″ φ E6012	170	Normal	Negative	Flat
3‡	3/16″ φ E6012	170	Normal	Negative	Flat
4‡	3/16″ φ E6012	200	Normal	Negative	Flat
5‡	3/16″ φ E6012	200	Normal	Negative	Flat

* See Fig. 12.
† See Fig. 16.
‡ See Fig. 12.

II. Partial-Penetration Butt Welds Connecting 7/8-in. A7 Steel Plates

4. *Description of Specimens*

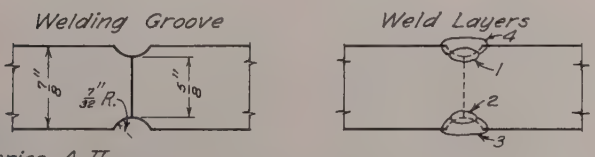
The specimens with longitudinal and transverse partial-penetration butt welds connecting 7/8-in. ASTM A7 steel plates are shown in Figs. 3 and 4. These figures show the over-all dimensions, and details of the weld groove and weld. There were two sizes of welds, one with a nominal penetration of 1/4 in. and the other with a nominal penetration of 3/16 in. The depth of the groove was 1/16 in. less than the nominal penetration — that is, 3/16 in. for 1/4-in. penetration



Series A-I & A-III
Reinforcement and mill scale on.

Series D-I
Reinforcement machined flush with plate and mill scale ground off. Draw-filed in direction of loading.

(a)—1/4-in. Partial-Penetration Butt Welds

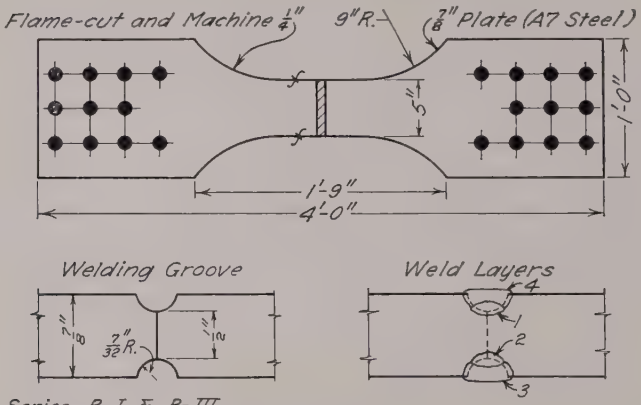


Series A-II
Reinforcement and mill scale on.

Series D-III
Reinforcement machined flush with plate and mill scale ground off. Draw-filed in direction of loading.

(b)—3/16-in. Partial-Penetration Butt Welds

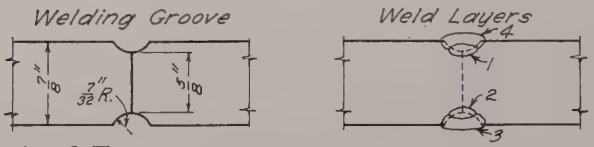
Fig. 3. 1/4-in. and 3/16-in. Partial-Penetration Longitudinal Butt Welds Connecting 7/8-in. A7 Steel Plates



Series B-I & B-III
Reinforcement and mill scale on.

Series D-II
Reinforcement machined flush with plate and mill scale ground off. Draw-filed in direction of loading.

(a)—1/4-in. Partial-Penetration Butt Welds



Series B-II
Reinforcement and mill scale on.

Series D-IV
Reinforcement machined flush with plate and mill scale ground off. Draw-filed in direction of loading.

(b)—3/16-in. Partial-Penetration Butt Welds

FIG. 4. 1/4-IN. AND 3/16-IN. PARTIAL-PENETRATION TRANSVERSE BUTT WELDS CONNECTING 7/8-IN. A7 STEEL PLATES

and 1/8 in. for 3/16-in. penetration. This penetration is based on the assumption that the fusion extended 1/16 in. into the base metal.

The Series B specimens described in Table 1 were examined by X-ray for flaws. A print of a typical radiograph of a weld with the reinforcement on is shown in Fig. 5. The radiographs indicated that the welds were all of excellent quality.

Three values of the unit stress, all based on the same total longitudinal load on the specimen, are reported for each specimen with a transverse partial-penetration butt weld. One value is based on the area of a transverse section of the plate adjacent to the weld; a second value is based on the gross area of the weld using the as-

sumed nominal penetration; the third value is based on the measured area of the weld fracture. Only one value of the unit stress due to a given load is reported for the specimens with longitudinal partial-penetration butt welds. It is based on the gross area of a transverse section of the plate.

All the above specimens were tested on a cycle in which the stress varied from 0 to tension, the temperature of the specimens being approximately 75 deg F for all tests except those of Series A-III and B-III. The latter were tested at approximately −20 deg F.

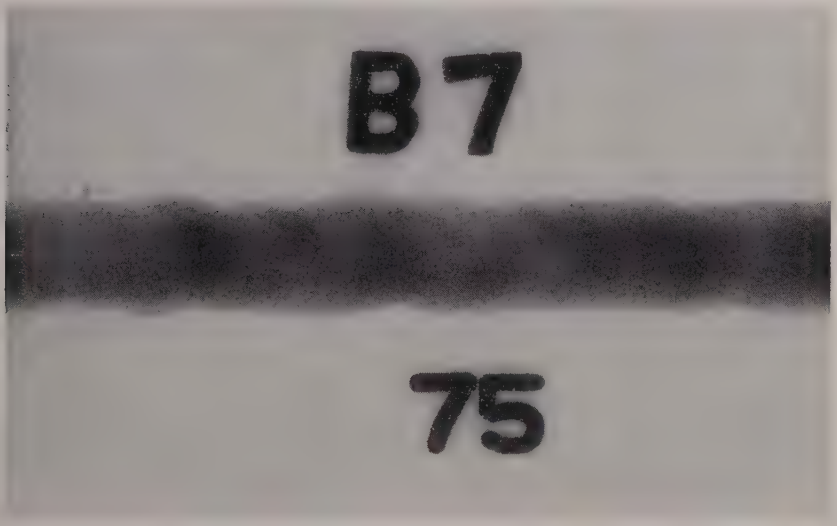


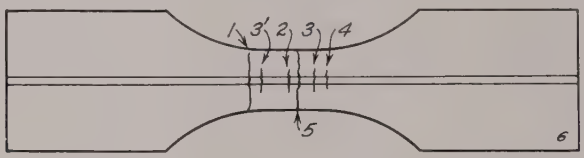
FIG. 5. TYPICAL RADIOGRAPH OF BUTT WELD FOR A SPECIMEN OF SERIES B

5. *Partial-Penetration Longitudinal Butt Welds*

The tests of partial-penetration longitudinal butt welds involve two series of specimens with welds and one series of specimens without welds: Series A-I with ¼-in. and Series A-II with $^{3}/_{16}$-in. longitudinal partial-penetration butt welds; and Series P-I, plates without welds. The specimens of both series with welds were tested at room temperature, with the reinforcement on, and without being stress-relieved. The specimens without welds, Series P-I, were also tested at room temperature. The results of the fatigue tests are given in Table 6 for Series A-I, in Table 7 for Series A-II, and in Table 8 for Series P-I. These data, plotted to a log-log scale, determine the

TABLE 6

SERIES A-I: FATIGUE STRENGTH OF LONGITUDINAL ¼-IN. PARTIAL-PENETRATION BUTT WELDS CONNECTING ⅞-IN. A7 STEEL PLATES



Specimen No.	Maximum Tension in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength* in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
A-16	30.0	2 721.7		30.0+	1
A-17	34.0	305.6	38.3	28.5	2
A-21	40.0	90.7	39.8		3 & 3'
A-23	30.0	759.8		27.3	4
A-26	36.0	158.1	37.7		4, 2 & 3'
A-27	32.0	232.4	34.8		3'
Av			37.6	28.6+	

RESULTS OF STATIC TEST—SPECIMEN A-30

Yield Strength = 38,400 p.s.i. Red. in Area = 29.6%
Ultimate Strength = 60,600 p.s.i. Elong. in 4 in. = 25.0%
Location of Fracture: 5

* Stress based on a value of K equal to 0.10 as shown in Fig. 6.

S-N diagrams of Fig. 6. The static strength of the fatigue-type specimens is given at the bottom of each of the tables for the welded specimens. The values of K used in the determination of $F_{100\,000}$ and $F_{2\,000\,000}$ are shown in Fig. 6; they were 0.10 for Series A-I and A-II, and 0.15 for Series P-I.

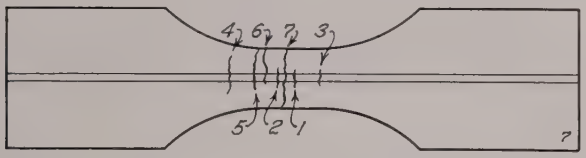
The average values of $F_{100\,000}$ and $F_{2\,000\,000}$ are 37,600 p.s.i. and 28,600 p.s.i. respectively for the ¼-in. partial-penetration welds of Series A-I. The corresponding values are 36,800 p.s.i. and 26,900 p.s.i. respectively for the $^3/_{16}$-in. partial-penetration welds of Series AII, and 44,500 p.s.i. and 29,500 p.s.i. for the Series P-I plates without welds.[1] The average strengths for Series A-I and A-II, when combined, are 37,200 p.s.i. and 27,750 p.s.i. for $F_{100\,000}$ and $F_{2\,000\,000}$ respectively.

The tests reported in Tables 6, 7, and 8 would seem to indicate that longitudinal partial-penetration butt welds as used in the speci-

[1] Values of 49,800 p.s.i. and 31,600 p.s.i. for $F_{100\,000}$ and $F_{2\,000\,000}$ are reported for similar ⅞-in. steel plates in Table 11, p. 23 of Univ. of Ill. Eng. Exp. Sta. Bul. 327.

TABLE 7

SERIES A-II: FATIGUE STRENGTH OF LONGITUDINAL 3/16-IN. PARTIAL-PENETRATION BUTT WELDS CONNECTING 7/8-IN. A7 STEEL PLATES



Specimen No.	Maximum Tension in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength* in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
A-1	34.7	135.0	35.8		1
A-2	30.0	646.0		26.8	2
A-6	31.6	503.6	37.2	27.5	3
A-8	28.0	1 628.9		27.4	4
A-12	29.0	670.9†		26.0	5
A-13	34.0	264.5	37.5		6
Av			36.8	26.9	

RESULTS OF STATIC TEST—SPECIMEN A-3

Yield Strength = 40,200 p.s.i. Red. in Area = 34.6%
Ultimate Strength = 62,600 p.s.i. Elong. in 4 in. = 40.5%
Location of Fracture: 7

* Stress based on a value of K of 0.10 as shown in Fig. 6.
† This specimen failed between 598,400 and 743,400 cycles; an average of 670,900 was used for calculations.

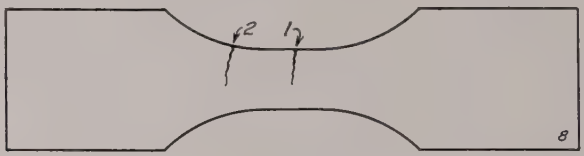
mens shown in Fig. 3 reduced the value of $F_{100\,000}$ by approximately 16 percent and the value of $F_{2\,000\,000}$ by approximately 6 percent below the corresponding values of the fatigue strength of similar plates without welds but with the mill scale on. They also indicate that the average fatigue strengths of 7/8-in. plates with 1/4-in. and with 3/16-in. longitudinal partial-penetration butt welds did not differ by a significant amount.

6. *Partial-Penetration Longitudinal Butt Welds: Reinforcement Off*

The specimens used in the tests described in this section were the same as those described in Section 5 except that the weld reinforcement and mill scale were machined and ground off, and draw-filed in the direction of loading. The tests included two series: Series D-I with 1/4-in. partial-penetration longitudinal butt welds, and Series D-III with 3/16-in. partial-penetration longitudinal butt welds.

TABLE 8

SERIES P-I: FATIGUE STRENGTH OF PLAIN SPECIMENS, 7/8-IN. A7 STEEL PLATES; MILL SCALE ON



Specimen No.	Maximum Tension in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength* in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
X-1	43.0	143.3	45.4		1
Y-1	34.0	491.1	42.5	27.5	2
Z-1	36.0	390.2	44.3	28.2	1
X-2	32.4	3 635.7		32.4+	2
Y-2	33.0	655.9		27.9	2
Z-2	40.0	244.3	45.7		2
Av			44.5	29.5+	

* Stress based on a value of K of 0.15 as shown in Fig. 6.

The results of the individual fatigue tests, given in Table 9 for Series D-I and in Table 10 for Series D-III, determine the S-N diagrams of Fig. 7. The value of K used in the determination of $F_{100\,000}$ and $F_{2\,000\,000}$ is 0.13 for both Series D-I and D-III. The average values of $F_{100\,000}$ and $F_{2\,000\,000}$ are 41,700 p.s.i. and 28,600 p.s.i. respectively for Series D-I, and 44,900 p.s.i. and 30,300 p.s.i. respectively for Series D-III. The corresponding values of the averages for the two series when combined are 43,300 and 29,450 p.s.i. These values are appreciably greater than the average values of 37,200 p.s.i. for $F_{100\,000}$ and 27,750 p.s.i. for $F_{2\,000\,000}$ for Series A-I and A-II, specimens similar to those of Series D-I and D-III except that the weld reinforcement and mill scale of the Series A-I and A-II specimens were not removed. Moreover, the average values of 43,300 and 29,450 p.s.i. for Series D-I and D-III, partial-penetration longitudinal butt welds with the reinforcement off, are very nearly the same as the corresponding values of 44,500 and 29,500 p.s.i. respectively for plates without welds, Series P-I of Section 5.

The tests reported in Tables 6, 7, 8, 9, and 10 and summarized in Table 11 indicate that, for 7/8-in. A7 steel plates with 1/4-in. and 3/16-in. longitudinal partial-penetration butt welds in the as-welded condition and *with the reinforcement on*, the values of $F_{100\,000}$ and $F_{2\,000\,000}$

are approximately 84 and 94 percent as great respectively as the corresponding values for similar plates without welds and with the mill scale on. However, for ⅞-in. A7 steel plates with ¼-in. and 3/16-in. longitudinal partial-penetration butt welds not stress-relieved

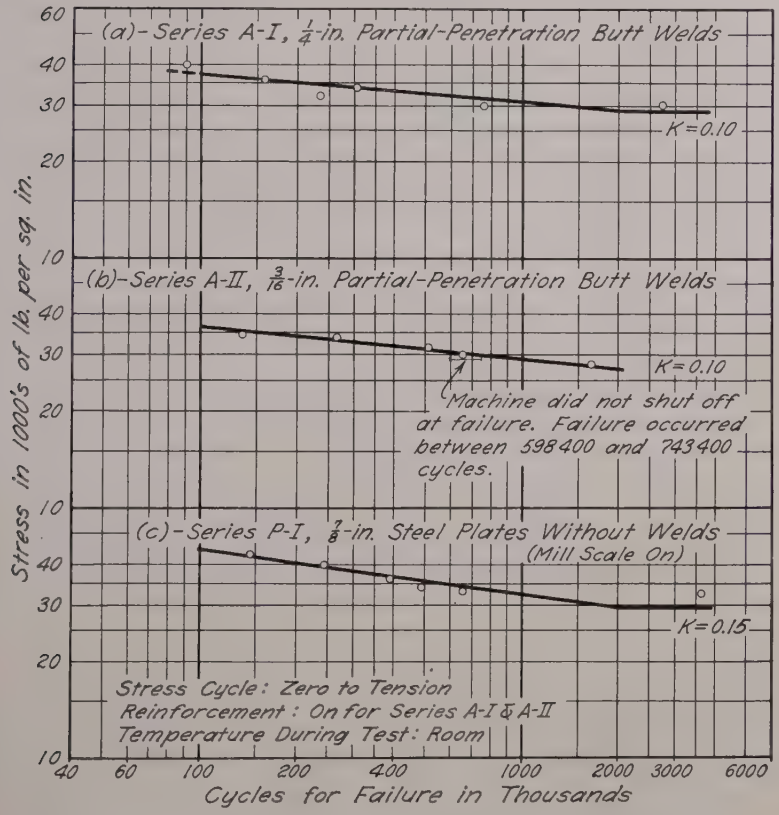
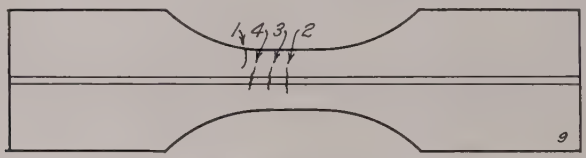


FIG. 6. *S-N* DIAGRAMS FOR ¼-IN. AND 3/16-IN. PARTIAL-PENETRATION LONGITUDINAL BUTT WELDS CONNECTING ⅞-IN. A7 STEEL PLATES AND FOR ⅞-IN. STEEL PLATES WITHOUT WELDS

but *with the reinforcement off*, the values of $F_{100\,000}$ and $F_{2\,000\,000}$ are very nearly the same as for similar plates without welds but with the mill scale on. The fact that the severe geometrical stress-raiser incident to the longitudinal partial-penetration weld had but little effect upon the fatigue strength is attributed to the orientation of the stress-raiser with respect to the direction of stress.

TABLE 9

SERIES D-I: FATIGUE STRENGTH OF LONGITUDINAL ¼-IN. PARTIAL-PENETRATION BUTT WELDS CONNECTING ⅞-IN. A7 STEEL PLATES; REINFORCEMENT AND MILL SCALE OFF

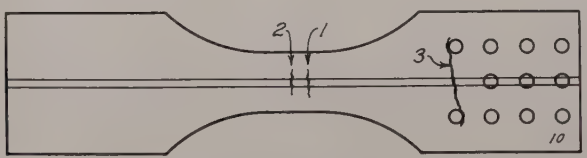


Specimen No.	Maximum Tension in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength* in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
D-1	40.0	213.1	44.0		1
D-2	32.2	572.9	40.4	27.4	2
D-3	35.0	511.2	43.3	29.7	3
D-4	43.1	74.4	41.4		3
D-5	32.0	514.6	39.6	27.2	4
A-22	30.0	2 464.0		30.0+	4
Av			41.7	28.6+	

* Stress based on a value of K of 0.13 as shown in Fig. 7.

TABLE 10

SERIES D-III: FATIGUE STRENGTH OF LONGITUDINAL 3/16-IN. PARTIAL-PENETRATION BUTT WELDS CONNECTING ⅞-IN. A7 STEEL PLATES; REINFORCEMENT AND MILL SCALE OFF



Specimen No.	Maximum Tension in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength* in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
D-11	36.0	574.6	45.2	30.6	1
D-12	34.0	529.9	42.3	28.6	2
D-13	43.4	219.4	48.0		2
D-14	44.8	85.5	43.9		1
D-15	32.0	1 006.0		29.3	1
A-7	34.0	1 552.0		32.9	3
Av			44.9	30.3	

* Stress based on a value of K of 0.13 as shown in Fig. 7.

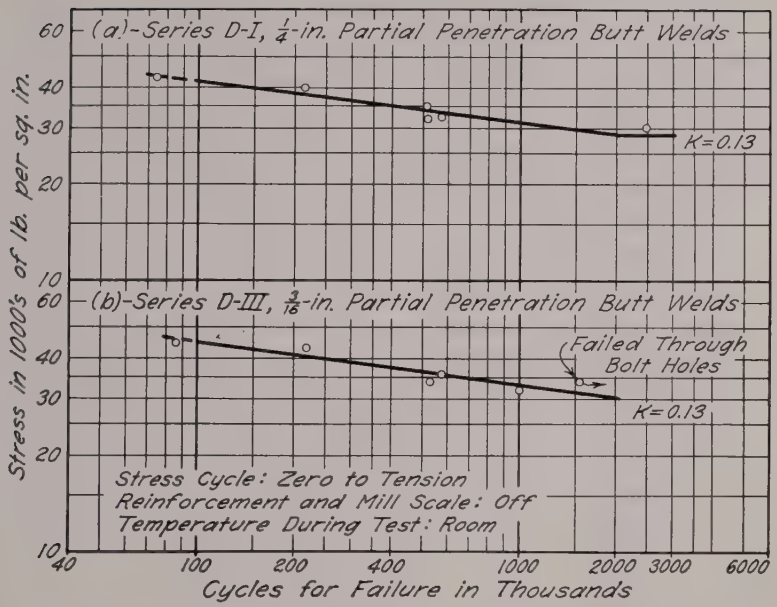


FIG. 7. *S-N* DIAGRAMS FOR ¼-IN. AND 3/16-IN. PARTIAL-PENETRATION LONGITUDINAL BUTT WELDS CONNECTING 7/8-IN. A7 STEEL PLATES; REINFORCEMENT AND MILL SCALE OFF

7. *Partial-Penetration Longitudinal Butt Welds Tested at −20 Deg F*

The specimens of this series, A-III, have the same geometrical characteristics as the specimens of Series A-I (Fig. 3). The tests of this series differ from those of Series A-I (Section 5) in that the specimens of this series were tested at −20 deg F while those of Series A-I were tested at room temperature, approximately 75 deg F.

The results of the individual fatigue tests, given in Table 12, determine the *S-N* diagram of Fig. 8. The dotted-line *S-N* diagram of the same figure represents the results for Series A-I, a series identical with A-III except for the temperature of testing. It would seem from the diagram of Fig. 8 that the fatigue strength of the partial-penetration longitudinal butt welds with reinforcement on and not stress-relieved was somewhat greater at −20 deg F than at room temperature.

8. *Partial-Penetration Transverse Butt Welds*

The tests of partial-penetration transverse butt welds involved two series: Series B-I with ¼-in. and Series B-II with 3/16-in. transverse partial-penetration butt welds. The details of the specimens

TABLE 11

FATIGUE STRENGTH OF PARTIAL-PENETRATION BUTT WELDS CONNECTING 7/8-IN. A7 STEEL PLATES: SUMMARY OF RESULTS

Series No.	Test Results		Nominal Penetration, in.	Weld Reinforcement	Temperature in Deg F During Test	$F_{100\,000}$ p.s.i.		$F_{2\,000\,000}$ p.s.i.	
	Table No.	Figure No.				Based upon Gross Area of Plate	Based upon Area of Weld Fracture	Based upon Gross Area of Plate	Based upon Area of Weld Fracture
Longitudinal Partial-Penetration Butt Weld									
A-I	6	6	1/4	On	Room	37 600		28 600	
A-II	7	6	3/16	On	Room	36 800		26 900	
D-I	9	7	1/4	Off	Room	41 700		28 600	
D-III	10	7	3/16	Off	Room	44 900		30 300	
Transverse Partial-Penetration Butt Weld									
B-I	13	9	1/4	On	Room	14 300	19 900	8 000	10 800
B-II	13	9	3/16	On	Room	12 400	24 500	6 950	12 000
D-II	14	10	1/4	Off	Room	10 700	19 500	8 400	13 900
D-IV	14	10	3/16	Off	Room	9 700	25 500	5 400	13 900
7/8-in. Plate Without Weld									
P-I	8	6			Room	44 500		29 500	
Partial-Penetration Butt Welds Tested at −20 Deg F*									
A-III	12	8	1/4	On	−20	41 000			
B-III	15	11	1/4	On	−20	20 000	27 500		

* The specimens of the A-III Series had longitudinal welds; those of the B-III Series had transverse welds.

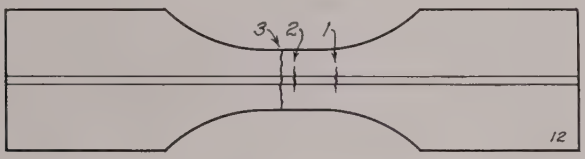
are shown in Fig. 4. For both series the specimens were tested at room temperature, with the reinforcement on and without being stress-relieved.

Three values of the unit stress are reported, all based upon the total axial load on the specimen and determined in the manner described in Section 4.

The results of the individual fatigue tests are reported in Table 13 for the specimens with 1/4-in. partial-penetration and for the specimens with 3/16-in. partial-penetration. The *S-N* diagrams for these series are given in Fig. 9. The results of all tests of partial-penetration transverse butt welds are summarized in Table 11.

TABLE 12

SERIES A-III: FATIGUE STRENGTH OF LONGITUDINAL ¼-IN. PARTIAL-PENETRATION BUTT WELDS CONNECTING ⅞-IN. A7 STEEL PLATES, TESTED AT −20 DEG F



Specimen No.	Maximum Tension in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength* in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
A-19	43.3	72.2	41.9		1
A-24	40.0	154.4	41.8		2
A-28	38.0	147.6	39.4		2
A-20	33.0	1 215.0+†		31.6+	
Av			41.0	31.6+	

RESULTS OF STATIC TEST—SPECIMEN A-18

Yield Strength = 45,200 p.s.i. Red. in Area = 13.5%
Ultimate Strength = 71,400 p.s.i. Elong. in 4 in. = 16.2%
Location of Fracture: 3

* Stress based on values of K of 0.10 as shown in Fig. 8.
† Test discontinued. Specimen did not fail.

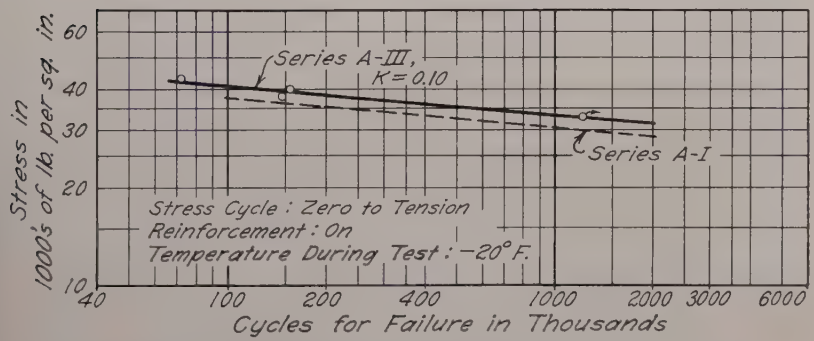
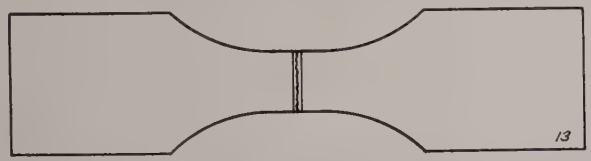


FIG. 8. SERIES A-III: *S-N* DIAGRAMS FOR ¼-IN. PARTIAL-PENETRATION LONGITUDINAL BUTT WELDS CONNECTING ⅞-IN. A7 STEEL PLATES, TESTED AT — 20 DEG F

TABLE 13

PART I—SERIES B-I: FATIGUE STRENGTH OF TRANSVERSE ¼-IN. PARTIAL-PENETRATION BUTT WELDS CONNECTING ⅞-IN. A7 STEEL PLATES



Specimen No.	Maximum Tension in 1000's p.s.i.			Number of Cycles for Failure in 1000's	Fatigue Strength in 1000's p.s.i.*						Location of Fracture (See Sketch)
					$F_{100\,000}$			$F_{2\,000\,000}$			
	Based on Gross Area of Plate	Based on Nominal Penetration	Based on Area of Fracture		Based on Gross Area of Plate	Based on Nominal Penetration	Based on Area of Fracture	Based on Gross Area of Plate	Based on Nominal Penetration	Based on Area of Fracture	
B-16	14.3	25.0	21.2	97.1	14.2	24.9	21.1				in weld
B-17	11.7	20.5	16.5	202.7	13.6	23.3	19.2				
B-21	17.1	30.0	24.1	50.2	14.8	26.5	20.7				
B-22	8.2	16.0	11.9	1 461.0				7.68	15.1	11.2	
B-26	8.55	15.0	11.0	3 045.0+				8.55+	15.0	11.0+	
B-27	10.3	18.0	13.6	524.8	14.6	24.3	19.6	7.78	14.1	10.1	
Av					14.3	24.8	19.9	8.0+	14.7+	10.8+	

RESULTS OF STATIC TEST—SPECIMEN B-24

Yield Strength = 42,700 p.s.i.†
Ultimate Strength = 58,100 p.s.i.†
Location of Fracture: in weld

* Based on values of K as shown in Fig. 9.
† Based upon area of fracture.

TABLE 13 (CONCLUDED)

PART II—SERIES B-II: FATIGUE STRENGTH OF TRANSVERSE $\frac{3}{16}$-IN. PARTIAL-PENETRATION BUTT WELDS CONNECTING $\frac{7}{8}$-IN. A7 STEEL PLATES

Specimen No.	Maximum Tension in 1000's p.s.i.			Number of Cycles for Failure in 1000's	Fatigue Strength in 1000's p.s.i.†						Location of Fracture (See Sketch)
					$F_{100\,000}$			$F_{2\,000\,000}$			
	Based on Gross Area of Plate	Based on Nominal Penetration	Based on Area of Fracture		Based on Gross Area of Plate	Based on Nominal Penetration	Based on Area of Fracture	Based on Gross Area of Plate	Based on Nominal Penetration	Based on Area of Fracture	
B-1	11.6	27.0	22.6	143.2	12.4	29.0	24.5				in
B-2	6.85	16.0	12.8	1 528.0				6.51	15.2	12.1	weld
B-6	7.25	17.0		7 524.3*				7.25+	17.0+		(*)
B-7	6.64	15.5		7 391 0*				6.64+	15.5+		(*)
B-11	8.60	20.0	14.2	726.7				7.08	16.3	11.3	in
B-12	7.27	17.0	12.7	2 237.3				7.27	17.0	12.7	weld
Av								6.95+	16.2+	12.0	

RESULTS OF STATIC TEST—SPECIMEN B-9

Yield Strength = 56,500 p.s.i.‡
Ultimate Strength = 58,100 p.s.i.‡
Location of Fracture: in weld

* Specimen did not fail.
† Based on values of K as shown in Fig. 9.
‡ Based upon area of fracture.

The average values for $F_{100\,000}$ and $F_{2\,000\,000}$ based on the area of the fracture were 19,900 p.s.i. and 10,800 p.s.i. respectively for the welds with a nominal penetration of ¼ in. The corresponding values are 24,500 p.s.i. and 12,000 p.s.i. respectively for the welds with a nominal penetration of $^3/_{16}$ in. The average values of $F_{100\,000}$ and $F_{2\,000\,000}$ for the two penetrations combined are 22,200 p.s.i. and 11,400

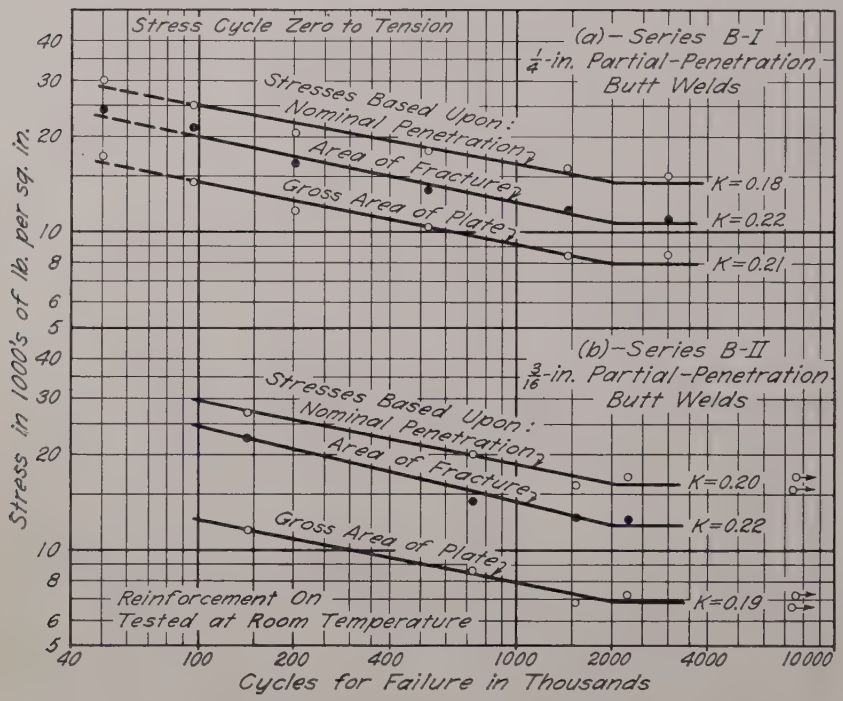


Fig. 9. Series B-I and B-II: *S-N* Diagrams for ¼-in. and $^3/_{16}$-in. Partial-Penetration Transverse Welds Connecting $^7/_8$-in. A7 Steel Plates

p.s.i. respectively. These values are based upon the area of the fracture and are comparable with values of 33,100 p.s.i. and 22,500 p.s.i. respectively for a good-quality, full-penetration, transverse butt weld in a $^7/_8$-in. plate.[1] Not only was the area of the fractured weld metal considerably less for the partial-penetration transverse weld than for a full-penetration transverse weld, but the unit fatigue strength was also considerably less.

The values of $F_{100\,000}$ and $F_{2\,000\,000}$ obtained by dividing the total

[1] Univ. of Ill. Eng. Exp. Sta. Bul. 327, Table 6, p. 17.

load by the transverse section of the plate adjacent to the weld are 14,300 p.s.i. and 8,000 p.s.i. for the specimens with ¼-in. partial-penetration butt welds, and 12,400 p.s.i. and 6,950 p.s.i. for the specimens with $^3/_{16}$-in. partial-penetration butt welds, respectively. These values are comparable with the 33,100 p.s.i. and 22,500 p.s.i., respectively, given in the previous paragraph for a good quality of full-penetration butt weld. They may also be compared with values of 44,500 p.s.i. and 29,500 p.s.i. for a ⅞-in. *plate without weld*.[1] That is, for a ⅞-in. A7 steel plate, the value of $F_{100\,000}$ based on the transverse section of the plate was 43 percent as great for a ¼-in. partial-penetration transverse butt weld as it was for a full-penetration transverse butt weld connecting similar plates. The corresponding value for $F_{2\,000\,000}$ was 36 percent. For the $^3/_{16}$-in. partial-penetration transverse butt welds, the corresponding values were 37 percent and 31 percent for $F_{100\,000}$ and $F_{2\,000\,000}$ respectively. Moreover, the ¼-in. and $^3/_{16}$-in. partial-penetration welds contain approximately 60 percent and 50 percent as much weld metal respectively as the full-penetration welds.

9. *Partial-Penetration Transverse Butt Welds: Reinforcement Off*

The tests described in this section include two series: Series D-II with ¼-in. and Series D-IV with $^3/_{16}$-in. partial-penetration transverse butt welds. These specimens differed from the specimens for Series B-I and B-II of Section 8 in that they were tested with the reinforcement machined and ground off, whereas the others were tested with the reinforcement on.

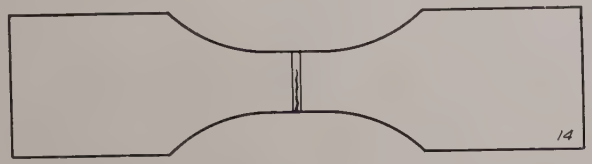
The results of the individual fatigue tests, given in Table 14, determine the *S-N* diagrams of Fig. 10. The values of $F_{100\,000}$ and $F_{2\,000\,000}$ based on the area of the fracture of the weld are 19,500 p.s.i. and 13,900 p.s.i. respectively for the ¼-in. partial-penetration welds, and 25,500 p.s.i. and 13,900 p.s.i. respectively for the $^3/_{16}$-in. partial-penetration welds. The averages for the two series are 22,500 p.s.i. and 13,900 p.s.i. respectively. These values are comparable with 22,200 p.s.i. and 11,400 p.s.i. for similar welds with the reinforcement and mill scale on.

The *unit* fatigue strength of the partial-penetration transverse butt welds connecting ⅞-in. A7 steel plates was increased by machining off the reinforcement. However, the effective area was reduced and the fatigue strength of the specimen as a whole was not affected by a significant amount.

[1] See Table 11, p. 26.

TABLE 14

PART I—SERIES D-II: FATIGUE STRENGTH OF TRANSVERSE ¼-IN. PARTIAL-PENETRATION BUTT WELDS CONNECTING ⅞-IN. A7 STEEL PLATES; REINFORCEMENT AND MILL SCALE OFF



Specimen No.	Maximum Tension in 1000's p.s.i.			Number of Cycles for Failure in 1000's	Fatigue Strength in 1000's p.s.i.*						Location of Fracture (See Sketch)
					$F_{100\,000}$			$F_{2\,000\,000}$			
	Based on Gross Area of Plate	Based on Nominal Penetration	Based on Area of Fracture		Based on Gross Area of Plate	Based on Nominal Penetration	Based on Area of Fracture	Based on Gross Area of Plate	Based on Nominal Penetration	Based on Area of Fracture	
D-6	9.0	16.0		4 265.0†				9.0+	16.0+		(†)
D-7	11.1	20.0	19.0	360.2	12.3	22.7	21.8	9.7	16.8	16.0	
D-8	10.1	18.0	17.5	247.4	10.9	19.7	19.2				in
D-9	9.0	16.0	15.5	558.8	10.3	19.0	18.4	8.1	14.1	13.6	weld
D-10	8.4	15.0	15.5	376.0	9.4	17.1	17.7	7.4	12.7	13.1	
B-19	8.6	15.0	14.3	650.4				7.9	13.4	12.8	
Av					10.7	19.9	19.5	8.4+	14.6+	13.9	

* Stress based on values of K as shown in Fig. 10.
† Specimen did not fail.

TABLE 14 (CONCLUDED)

PART II—SERIES D-IV: FATIGUE STRENGTH OF TRANSVERSE 3/16-IN. PARTIAL-PENETRATION BUTT WELDS CONNECTING 7/8-IN. A7 STEEL PLATES; REINFORCEMENT AND MILL SCALE OFF

Specimen No.	Maximum Tension in 1000's p.s.i.			Number of Cycles for Failure in 1000's	Fatigue Strength in 1000's p.s.i.*						Location of Fracture (See Sketch)
					$F_{100\,000}$			$F_{2\,000\,000}$			
	Based on Gross Area of Plate	Based on Nominal Penetration	Based on Area of Fracture		Based on Gross Area of Plate	Based on Nominal Penetration	Based on Area of Fracture	Based on Gross Area of Plate	Based on Nominal Penetration	Based on Area of Fracture	
D-16	7.6	18.0	20.1	357.0	9.7	23.5	25.6	5.5	13.0	14.5	
D-17	5.9	14.0		3 568.2†				5.9+	14.0+		in
D-18	6.4	15.0	15.6	682.9				5.2	12.0	12.7	weld
D-19	6.7	16.0	18.6	476.0	9.1	22.2	25.0	5.1	11.8	14.2	
D-20	8.4	20.0	21.7	264.0	10.2	24.5	26.1				
B-4	6.1	14.0	16.8	815.1				5.2	11.6	14.2	
Av					9.7	23.4	25.5	5.4+	12.5+	13.9	

* Stress based on values of K as shown in Fig. 10.
† Specimen did not fail.

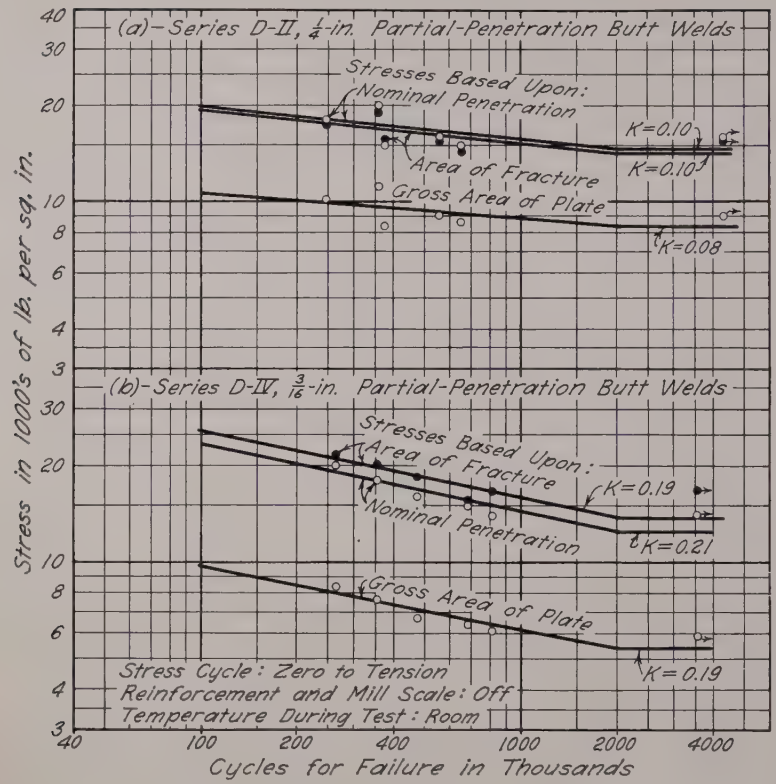


Fig. 10. Series D-II and D-IV: *S-N* Diagrams for ¼-in. and 3/16-in. Partial-Penetration Transverse Welds Connecting ⅞-in. A7 Steel Plates; Reinforcement and Mill Scale Off

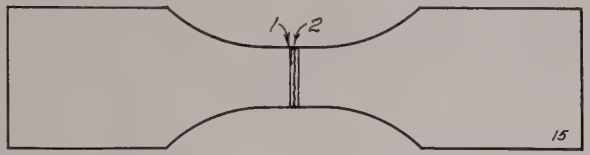
10. *Partial-Penetration Transverse Butt Welds Tested at −20 Deg F*

The specimens for Series B-III, ¼-in. partial-penetration transverse butt welds with the reinforcement on, were geometrically identical with the specimens of Series B-I (Fig. 4). This series differs from Series B-I (Section 8) in that the specimens of this series were tested at −20 deg F, whereas those of Series B-I were tested at room temperature, approximately 75 deg F. Both were tested with the reinforcement on and without being stress-relieved.

The results of the individual fatigue tests, given in Table 15, determine the *S-N* diagrams of Fig. 11. The dotted-line *S-N* diagrams of the same figure represent the results of Series B-I, the series identical with B-III except for the temperature of testing.

Table 15

Series B-III: Fatigue Strength of Transverse ¼-in. Partial-Penetration Butt Welds Connecting ⅞-in. A7 Steel Plates, Tested at −20 Deg F



Specimen No.	Maximum Tension in 1000's p.s.i.			Number of Cycles for Failure in 1000's	Fatigue Strength in 1000's p.s.i.*						Location of Fracture (See Sketch)
					$F_{100\,000}$			$F_{2\,000\,000}$			
	Based on Gross Area of Plate	Based on Nominal Penetration	Based on Area of Fracture		Based on Gross Area of Plate	Based on Nominal Penetration	Based on Area of Fracture	Based on Gross Area of Plate	Based on Nominal Penetration	Based on Area of Fracture	
B-18	13.7	24.0	17.7	405.0	18.7	30.8	24.8				2
B-23	15.4	27.0	21.8	335.0	20.1	33.6	29.1				2
B-28	18.9	33.0	25.4	164.5	21.1	36.1	28.6				1
Av					20.0	33.5	27.5				

Results of Static Test—Specimen B-29

Yield Strength = 53,200 p.s.i.†
Ultimate Strength = 73,300 p.s.i.†
Location of Fracture: 2

* Based on values of K as shown in Fig. 11.
† Stress based upon area of fracture.

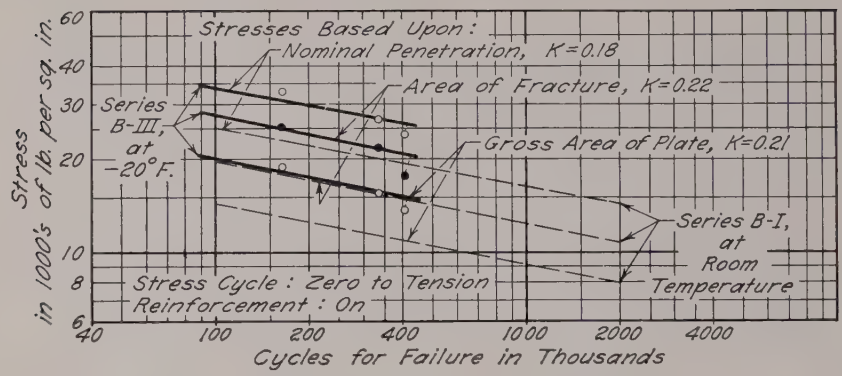


Fig. 11. Series B-III: *S-N* Diagram for ¼-in. Partial-Penetration Transverse Butt Welds Connecting ⅞-in. A7 Steel Plates, Tested at — 20 Deg F

The limited number of tests of identical transverse ¼-in., partial-penetration butt welds connecting ⅞-in. A7 steel plates indicated that the fatigue strength was somewhat greater for those tested at −20 deg F than for those tested at approximately 75 deg F.

III. Transverse Single-V Butt Welds Connecting ½-in. A7 Steel Plates

11. *Description of Specimens*

There were four series of fatigue tests of transverse single-V butt welds connecting ½-in. A7 steel plates. These were designated as Series F-I, F-III, H-I, and H-II. The details of the specimens and the welding procedure are shown in Fig. 12. The specimens for the two F series were cut from the parent plate F, and the specimens for the two H series were cut from the parent plate H; both are

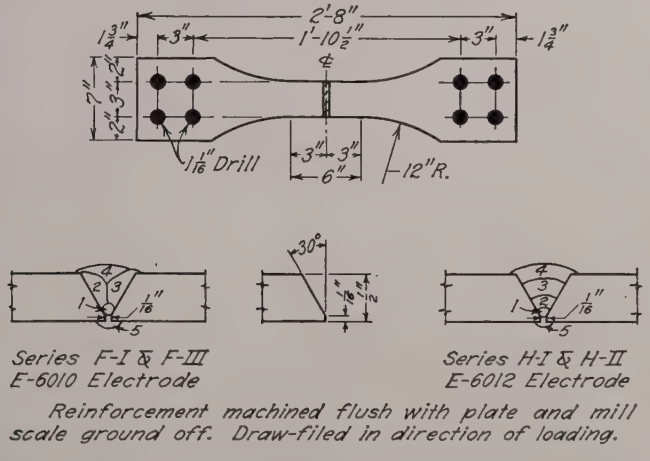


Fig. 12. Single-V Transverse Butt Welds Connecting ½-in. A7 Steel Plates (Details of Specimens)

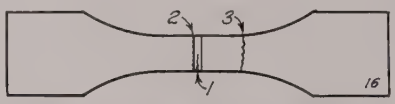
shown in Fig. 2. The two parent plates, however, were from the same heat. The specimens for Series F-I and F-III were welded with E6010 electrodes, those for Series H-I and H-II with E6012 electrodes. The weld reinforcement and the mill scale were removed from the specimens of all series by the method described in Fig. 12. The specimens of Series F-III and H-II were then stress-relieved by the "high-temperature" method described on page 45.

The specimens of Series F-V, plain plates without welds, cut from the parent plate F as shown in Fig. 2, were used as control specimens. They were tested with the mill scale on.

All these above fatigue specimens were tested on a cycle in which the stress varied from 0 to tension, the temperature of testing being approximately 75 deg F for all tests.

TABLE 16

SERIES F-I: FATIGUE STRENGTH OF TRANSVERSE BUTT WELDS CONNECTING ½-IN. A7 STEEL PLATES; REINFORCEMENT AND MILL SCALE OFF; E6010 ELECTRODE



Specimen No.	Maximum Tension* in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength* in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
F1	30.7	1 424.4		30.0	1
F2	36.0	262.6	38.5		1
F3	34.0	105.0	34.2		1
F4	35.0	269.8	37.6		1
F5	33.0	370.9	36.2	29.3	1
F6	31.0	274.2	33.3		1
F7	30.0	568.0†	33.9	27.5	2
Av			35.6	28.9	

RESULTS OF STATIC TEST—SPECIMEN F-8

Yield Strength = 36,200 p.s.i. Red. in Area = 51%
Ultimate Strength = 63,800 p.s.i. Elong. in 4 in. = 28%
Location of Fracture: 3

* Stress based on gross area of plate. $K = 0.07$ as shown in Fig. 13.
† This specimen failed between 420,800 and 714,200 cycles; the average—568,000—was used for calculations.

12. *Results of Tests*

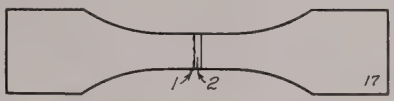
The results of the individual fatigue tests of transverse single-V butt welds connecting ½-in. plates are given in Tables 16, 17, and 18 for Series F-I, F-III, and F-V respectively, and in Tables 19 and 20 for Series H-I and H-II. The data from these tests, plotted to a log-log scale, determine the *S-N* diagrams of Figs. 13, 14, and 15. The value of K for each series is given on the diagram for that series. A summary of the average values of the fatigue strengths for the various series is presented in Table 21.

The values of the fatigue strength of welded specimens with the weld reinforcement and mill scale off, summarized in Table 21, are the basis for the following statements.

The average of the values of $F_{100\,000}$ for Series F-I and H-I, specimens that had not been stress-relieved, was 36,850 p.s.i. The corresponding average value for similar specimens that had been stress relieved by the high-temperature method, Series F-III and H-II, is

TABLE 17

SERIES F-III: FATIGUE STRENGTH OF TRANSVERSE BUTT WELDS CONNECTING ½-IN. A7 STEEL PLATES, STRESS-RELIEVED BY THE HIGH-TEMPERATURE METHOD; REINFORCEMENT AND MILL SCALE OFF; E6010 ELECTRODE



Specimen No.	Maximum Tension* in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength* in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
F17	32.0	1 185.2		30.4	1
F18	30.0	556.0†	35.9	26.4	1
F19	28.0	3 154.8‡		28.0+	..
F20	36.0	275.4	39.9		2
F21	31.0	3 890.5		31.0+	2
F22	34.0	538.6	40.2	29.5	2
F23	39.0	172.7	41.2		2
Av			39.3	29.1+	

RESULTS OF STATIC TEST—SPECIMEN F-24

Yield Strength = 32,900 p.s.i. Red. in Area = 30%
Ultimate Strength = 56,800 p.s.i. Elong. in 4 in. = 26%
Location of Fracture: 1

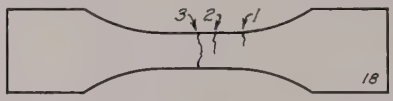
* Stress based on gross area of plate. $K = 0.10$ as shown in Fig. 13.
† This specimen failed between 458,400 and 652,800 cycles; the average—556,000—was used for calculations.
‡ Specimen did not fail.

38,050 p.s.i., a value 3.3 percent greater. The average of the values of $F_{2\,000\,000}$ for the same specimens that had not been stress-relieved is 27,700 p.s.i.; the corresponding average value for the seven specimens that had been stress-relieved is 30,150 p.s.i., a value 8.8 percent greater. For all these specimens the reinforcement and mill scale had been removed. Apparently the high-temperature method of stress-relieving had no very significant effect on the fatigue strength of these welded specimens with the reinforcement off.

The average of the values of $F_{100\,000}$ for the specimens that had been welded with an E6010 electrode, Series F-I and F-III, is 37,450 p.s.i. The corresponding average value for the specimens that had been welded with an E6012 electrode, Series H-I and H-II, is likewise 37,450 p.s.i. The average of the values of $F_{2\,000\,000}$ for the same specimens that had been welded with an E6010 electrode is 29,000 p.s.i. The corresponding average value for the specimens that had

TABLE 18

SERIES F-V: FATIGUE STRENGTH OF PLAIN SPECIMENS, ½-IN. A7 STEEL PLATES



Specimen No.	Maximum Tension in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength† in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
FP1	36.0	1 902.2		35.8	1
FP2	32.0	3 744.6*		32.0+	..
FP3	37.0	817.9		33.4	2
FP4	43.7	413.0	50.4	37.2	2
FP5	47.8	100.7	47.8		1
FP6	35.0	3 586.0		35.0+	1
FP7	34.0	4 677.6*		34.0+	..
Av			49.1	34.7+	

RESULTS OF STATIC TEST—SPECIMEN FP-8

Yield Strength = 34,700 p.s.i. Red. in Area = 50%
Ultimate Strength = 58,500 p.s.i. Elong. in 4 in. = 45%
Location of Fracture: 3

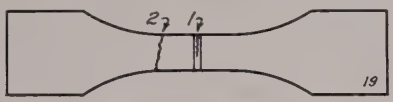
* Specimen did not fail.
† Stress based on value of $K = 0.10$ as shown in Fig. 14.

been welded with an E6012 electrode is 28,850 p.s.i. Apparently, single-V transverse butt welds connecting ½-in. A7 steel plates had very much the same fatigue strength whether they were welded with E6010 or with E6012 electrodes.

Previous fatigue tests of butt welds connecting ½-in., ¾-in., and ⅞-in. plates were reported in University of Illinois Engineering Experiment Station Bulletins 310, 327, and 344. As an indication of the effect of the plate thickness upon the fatigue strength of butt-weld joints with the reinforcement machined off, the results of the tests of Series F-I, F-III, H-I, and H-II are compared in Table 22 with results reported in former bulletins. These values indicate that the plate thickness had no significant effect on the strength of the joints in the three plate thicknesses listed, and in the types of joints listed. The average fatigue strengths for the joints in ½-, ¾-, and ⅞-in. plates not stress-relieved and with the weld reinforcement removed are 27,700, 27,900, and 27,300 p.s.i. respectively. The average strengths for the same type of joint stress-relieved are 30,100 and 27,800 p.s.i. for ½-in. and ⅞-in. plates respectively.

Table 19

Series H-I: Fatigue Strength of Transverse Butt Welds Connecting 1½-in. A7 Steel Plates; Reinforcement and Mill Scale Off; E6012 Electrode



Specimen No.	Maximum Tension in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength† in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
H1	34.0	184.7	36.6		1
H2	40.0	136.0	41.5		1
H3	30.0	999.6		27.6	1
H4	32.0	246.5	35.7		1
H5	28.0	879.5		25.3	1
H6	26.0	2 892.0*		26.0+	..
H7	33.0	388.7	38.8	27.1	1
Av			38.1	26.5+	

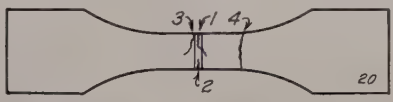
Results of Static Test—Specimen H-8

Yield Strength = 35,300 p.s.i. Red. in Area = 51%
Ultimate Strength = 60,100 p.s.i. Elong. in 4 in. = 32%
Location of Fracture: 2

* Specimen did not fail.
† Stress based on gross area of plate. $K = 0.12$ as shown in Fig. 15.

Table 20

Series H-II: Fatigue Strength of Transverse Butt Welds Connecting 1½-in. A7 Steel Plates, Stress-Relieved by the High-Temperature Method; Reinforcement and Mill Scale Off; E6012 Electrode

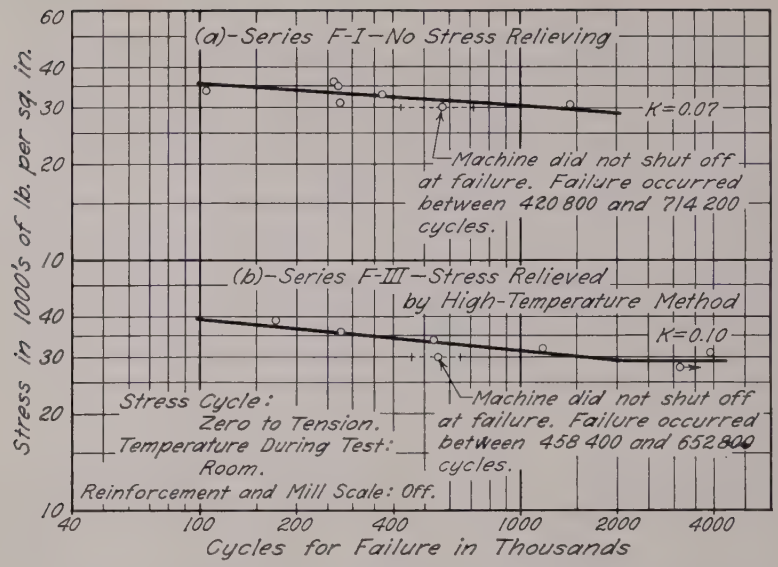


Specimen No.	Maximum Tension* in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength* in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
H9	34.0	238.8	36.2		1
H10	39.1	82.8	38.2		2
H11	30.0	2 005.2		30.0	2
H12	32.0	563.7	36.1	29.3	2
H13	36.0	606.3		33.1	3
H14	34.0	1 000.1		32.6	..
Av			36.8	31.2	

Results of Static Test—Specimen H-16

Yield Strength = 35,200 p.s.i. Red. in Area = 51%
Ultimate Strength = 58,100 p.s.i. Elong. in 4 in. = 37%
Location of Fracture: 4

* Stress based on gross area of plate. $K = 0.07$ as shown in Fig. 15.


(a)-Series F-I—No Stress Relieving
K=0.07
Machine did not shut off at failure. Failure occurred between 420 800 and 714 200 cycles.
(b)-Series F-III—Stress Relieved by High-Temperature Method
K=0.10
Machine did not shut off at failure. Failure occurred between 458 400 and 652 800 cycles.
Stress Cycle: Zero to Tension.
Temperature During Test: Room.
Reinforcement and Mill Scale: Off.
Stress in 1000's of lb. per sq. in.
Cycles for Failure in Thousands

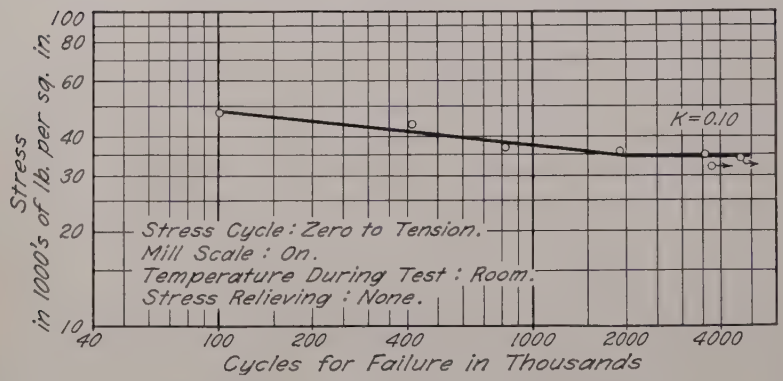

K=0.10
Stress Cycle: Zero to Tension.
Mill Scale: On.
Temperature During Test: Room.
Stress Relieving: None.
Stress in 1000's of lb. per sq. in.
Cycles for Failure in Thousands

FIG. 13 (ABOVE). SERIES F-I AND F-III: *S-N* DIAGRAMS FOR SINGLE-V TRANSVERSE BUTT WELDS CONNECTING ½-IN. A7 STEEL PLATES. E6010 ELECTRODE. REINFORCEMENT AND MILL SCALE OFF. WITH AND WITHOUT STRESS-RELIEVING

FIG. 14 (BELOW). SERIES F-V: *S-N* DIAGRAM FOR ½-IN. A7 STEEL PLATES WITHOUT WELD

Table 23 presents a similar tabulation of the fatigue strength of butt-weld joints with the reinforcement on. In this table the joints in the ½-in. plate appear to be slightly stronger, but the difference is not significant. The effect of stress relieving was to increase the fatigue strength of the joint slightly. The largest increase in fatigue strength, however, is due to the removal of the weld reinforcement, which while removing weld metal also decreases the geometrical stress-raiser caused by the weld reinforcement.

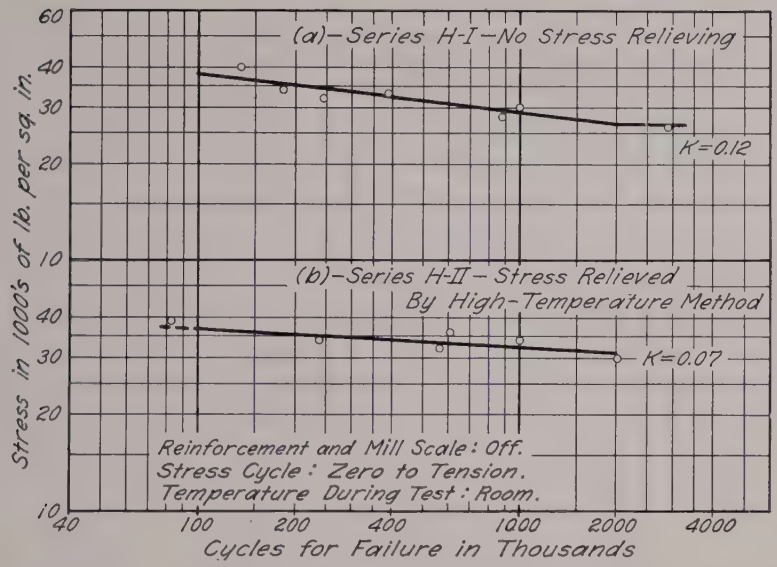


FIG. 15. SERIES H-I AND H-II: *S-N* DIAGRAMS FOR SINGLE-V TRANSVERSE BUTT WELDS CONNECTING ½-IN. A7 STEEL PLATES. E6012 ELECTRODE. REINFORCEMENT AND MILL SCALE OFF. WITH AND WITHOUT STRESS-RELIEVING

TABLE 21

SUMMARY OF RESULTS: FATIGUE STRENGTH OF SINGLE-V TRANSVERSE BUTT WELDS CONNECTING ½-IN. A7 STEEL PLATES

Series No.	Description of Specimen	$F_{100\,000}$ p.s.i.	$F_{2\,000\,000}$ p.s.i.	K
F-I	Reinforcement and Mill Scale Off. E6010 Electrode. Not Stress-Relieved	35 600	28 900	0.07
F-III	Reinforcement and Mill Scale Off. E6010 Electrode. Stress-Relieved by High-Temperature Method	39 300	29 100+	0.10
F-V	Plain ½-in. A7 Steel Plate. Mill Scale On	49 100	34 700+	0.10
H-I	Reinforcement and Mill Scale Off. E6012 Electrode. Not Stress-Relieved	38 100	26 500+	0.12
H-II	Reinforcement and Mill Scale Off. E6012 Electrode. Stress-Relieved by High-Temperature Method	36 800	31 200	0.07

TABLE 22

FATIGUE STRENGTH OF TRANSVERSE BUTT-WELD JOINTS IN PLATES OF VARIOUS THICKNESSES; REINFORCEMENT MACHINED OFF

Line	Plate Thickness, in.	Reference			Type of Weld	Stress-Relieved	Weld Reinf.	Fatigue Strength in p.s.i. (Stress Cycle 0 to tension) $F_{2\,000\,000}$
		Bul. No.	Page	Table				
1	¾	310	18	5	Single-V	No	Off	27 900
2	⅞	327	21	9	Single-U	Yes	Off	27 800
3	⅞	327	22	10	Single-U	No	Off	26 300
4	⅞	327	20	8	Single-U	No	Off	28 400
5	½	Series F-I			Single-V	No	Off	28 900
6	½	Series F-III			Single-V	Yes	Off	29 100
7	½	Series H-I			Single-V	No	Off	26 500
8	½	Series H-II			Single-V	Yes	Off	31 200

TABLE 23

FATIGUE STRENGTH OF TRANSVERSE BUTT-WELD JOINTS IN PLATES OF VARIOUS THICKNESSES; REINFORCEMENT ON

Line	Plate Thickness, in.	Reference			Type of Weld	Stress-Relieved	Weld Reinf.	Fatigue Strength in p.s.i. $F_{2\,000\,000}$†
		Bul. No.	Page	Table				
1	½	327	60	26	Single-V	No	On	26 400
2	¾	310	18	5	Single-V*	No	On	22 800
3	¾	310	18	5	Single-V	No	On	21 800
4	¾	310	18	5	Single-V*	Yes	On	25 800
5	¾	310	18	5	Single-V	Yes	On	23 200
6	⅞	327	17	6	Single-U	No	On	22 500
7	⅞	327	19	7	Single-U	Yes	On	23 700
8	⅞	344	17	4	Single-U	No	On	21 500
9	⅞	344	16	3	Double-V	No	On	21 100
10	⅞	344	18	5	Double-V	No	On	21 200
11	⅞	344	75	17	Double-V	No	On	23 100
12	⅞	344	75	18	Double-V	No	On	21 300
13	⅞	344	76	19	Double-V	No	On	22 200

* Automatic-welded; all others hand-welded.
† Each value is the average for a series, usually consisting of three tests.

IV. Longitudinal Single-V Butt Welds Connecting ½-in. A7 Steel Plates

13. *Description of Specimens*

There were eight series of tests of longitudinal single-V butt welds connecting ½-in. A7 steel plates, designated as G-I to G-VI inclusive, and H-III and H-IV. All specimens were welded with E6010 electrodes, and all tests were made at approximately 75 deg F. All specimens for the G series were cut from one plate; all specimens for the H series, from a second plate. Both plates were from the same heat. The location of the specimens in the parent plate is shown in Fig. 2. The details of the specimens and the welding procedures are shown in Fig. 16. The specimens for Series G-I, G-II, G-III, and H-III were tested with the reinforcement on. However, for specimens of Series G-IV, G-V, G-VI, and H-IV, the reinforcement and mill scale were removed by machining, and the surfaces were polished.

All these specimens were tested on a cycle in which the stress varied from 0 to tension, the temperature of the specimens being approximately 75 deg F for all tests. The specimens of Series G-II and G-V were stress-relieved by the "high-temperature" stress-relieving method, the specimens of Series G-III and G-VI were stress-relieved "mechanically," and the specimens of Series H-III and H-IV were stress-relieved by the "low-temperature" method.

The three stress-relieving methods are described in the following paragraphs.

"High-Temperature" Stress-Relieving Method

a. The specimens were placed in a furnace at room temperature, and the temperature of the furnace was raised at an arbitrary rate to 300 deg F.

b. The temperature of the furnace was then raised at the rate of 200 deg F per hr until a temperature of 1150 deg F was attained.

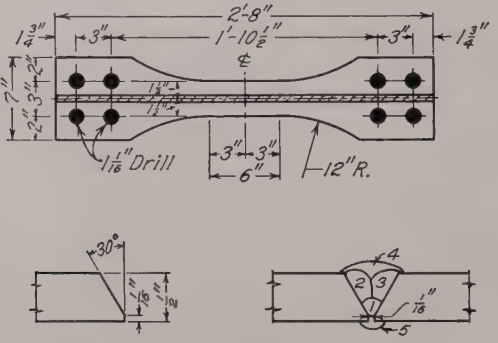
c. The temperature of the furnace was held at 1150 deg F for 30 min.

d. The heat of the furnace was then cut off and the furnace was allowed to cool to 300 deg F at a rate of approximately 200 deg per hr with the door closed.

e. The furnace doors were then opened, and the specimens were removed when they had cooled to a temperature convenient for handling.

"Low-Temperature" Stress-Relieving Method

The specimens stress-relieved by the low-temperature method were heated symetrically on each side of the weld with 2-in. wide flame priming heads. These were located 5 in. on centers, and traveled in the longitudinal direction of the specimens. This heated bands 2 in. wide along the outer edges of the plate without heating the weld. An air-water spray was applied 6 in. back of the advancing flames. The speed of travel was approximately 20 in. per min for the advancing flames. The temperature observed with Tempilstiks applied on the underside of the plates indicated a 350 deg F heat-band $1^{13}/_{16}$ in. wide and a 400 deg F heat-band $1\frac{1}{2}$ in. wide.



Series G-I, G-II, G-III & H-III
Reinforcement and mill scale on.

Series G-IV, G-V, G-VI & H-IV
Reinforcement machined flush with plate and mill scale ground off. Draw-filed in direction of loading.

Fig. 16. Single-V Longitudinal Butt Weld Connecting ½-in. A7 Steel Plates (Details of Specimens)

"Mechanical" Stress-Relieving Method

The specimens subjected to the mechanical stress-relieving method were pulled in tension to a plastic elongation of 0.009 in. per in.

The sequence of operations for fabricating the specimens of the stress-relieved series is given in Table 24.

14. *Results of Tests: Effect of Stress-Relieving*

The results of the fatigue tests for Series G-I, G-II, G-III, and H-III, welds with the reinforcement on, are given in Tables 25–28. The *S-N* diagrams for the same series are given in Fig. 17. The results of the fatigue tests for Series G-IV, G-V, G-VI, and H-IV,

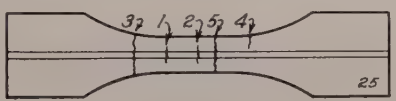
Table 24

Sequence of Operations After Welding for Preparation of Stress-Relieved Specimens

Series No.	Operation Number			
	1	2	3	4
H-II	Flame cut to approximate shape	High-temperature stress-relieving	Machine to shape	Machine off reinforcement
H-III	Low-temperature stress-relieving	Saw-cut to approximate shape	Machine to shape	
H-IV	Low-temperature stress-relieving	Saw-cut to approximate shape	Machine to shape	Machine off reinforcement
G-II	Flame cut to approximate shape	High-temperature stress-relieving	Machine to shape	
G-III	Mechanical stress-relieving	Saw-cut to approximate shape	Machine to shape	
G-V	Machine off reinforcement	Flame cut to approximate shape	High-temperature stress-relieving	Machine to shape
G-VI	Mechanical stress-relieving	Saw-cut to approximate shape	Machine to shape	Machine off reinforcement
F-III	Flame cut to approximate shape	High-temperature stress-relieving	Machine to shape	Machine off reinforcement

Table 25

Series G-I: Fatigue Strength of Longitudinal Butt Welds Connecting ½-in. A7 Steel Plates; E6010 Electrode



Specimen No.	Maximum Tension in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength* in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
G1	32.0	280.6	37.3		1
G2	34.0	254.8	39.2		2
G3	28.0	681.9		23.8	1
G4	30.7	357.1	37.2	23.2	3
G5	27.0	1 490.7		25.8	2
G6	26.0	1 288.9		24.3	4
G7	37.0	172.3	40.2		1
Av			38.5	24.3	

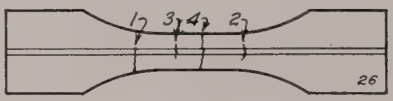
Results of Static Test—Specimen G-8

Yield Strength = 43,700 p.s.i. Red. in Area = 30%
Ultimate Strength = 64,300 p.s.i. Elong. in 4 in. = 21%
Location of Fracture: 5

* Stress based on gross area of plate. $K = 0.15$ as shown in Fig. 17.

Table 26

Series G-II: Fatigue Strength of Longitudinal Butt Welds Connecting ½-in. A7 Steel Plates, Stress-Relieved by the High-Temperature Method; Reinforcement On



Specimen No.	Maximum Tension in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength* in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
G9	30.0	840.4		26.6	1
G10	34.0	448.0	42.0		2
G11	36.0	160.9	38.6		3
G12	27.0	1 023.4		24.6	3
G13	39.0	128.4	40.4		3
G14	27.0	1 349.7		25.6	2
Av			40.3	26.1	

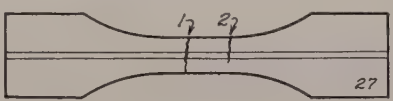
Results of Static Test—Specimen G-16

Yield Strength = 40,100 p.s.i. Red. in Area = 49%
Ultimate Strength = 61,000 p.s.i. Elong. in 4 in. = 42%
Location of Fracture: 4

* Stress based on gross area of plate. $K = 0.14$ as shown in Fig. 17.

Table 27

Series G-III: Fatigue Strength of Longitudinal Butt Welds Connecting ½-in. A7 Steel Plates, Stress-Relieved by the Mechanical Method; Reinforcement On



Specimen No.	Maximum Tension* in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength* in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
G17	43.5	89.2	42.8		1
G18	34.0	327.5	39.6	27.0	1
G19	32.0	726.8		28.3	2
G20	38.2	123.0	39.5		2
G21	30.0	1 255.5		28.3	2
G22	32.0	955.4		29.2	2
G23	30.0	594.3	37.7	25.8	1
Av			39.9	27.7	

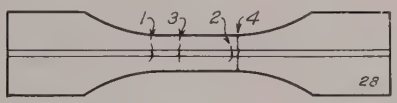
Results of Static Test—Specimen G-24

Yield Strength = 45,400 p.s.i. Red. in Area = 24%
Ultimate Strength = 64,800 p.s.i. Elong. in 4 in. = 17%
Location of Fracture: 1

* Stress based on gross area of plate. $K = 0.13$ as shown in Fig. 17.

TABLE 28

SERIES H-III: FATIGUE STRENGTH OF LONGITUDINAL BUTT WELDS CONNECTING ½-IN. A7 STEEL PLATES, STRESS-RELIEVED BY THE LOW-TEMPERATURE METHOD; REINFORCEMENT ON



Specimen No.	Maximum Tension* in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength* in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
H18	40.0	568.4	55.6	31.5	1
H19	42.0	321.7	52.4	29.7	2
H20	46.0	60.2	41.7		3
H21	28.0	2 190.3		28.0+	3
H22	28.0	1 531.9		26.6	2
H23	30.0	760.0		25.0	1
Av			49.9	28.2	

RESULTS OF STATIC TEST—SPECIMEN H-24

Yield Strength = 43,000 p.s.i. Red. in Area = 36%
Ultimate Strength = 65,500 p.s.i. Elong. in 4 in. = 33%
Location of Fracture: 4

* Stress based on gross area of plate. $K = 0.19$ as shown in Fig. 17.

welds with the reinforcement off, are given in Tables 29–32. The *S-N* diagrams for these latter series are given in Fig. 18.

The values of the fatigue strength given in Tables 25–32 are summarized in Table 33. The average values for the specimens with the reinforcement on are given in the upper part of the table, the average values for the specimens with the reinforcement off are given in the middle part, and the averages of the two sets of values are given in the lower part. The results of the static tests are given in the right-hand part of the same table. The fatigue and static strengths are expressed in p.s.i. and also in percentages of the corresponding strength of the specimens that were not stress-relieved.

The values of the fatigue strength given in Table 33 are, in general, the averages from three tests in each of four categories: $F_{100\,000}$ and $F_{2\,000\,000}$ for both reinforcement on and reinforcement off. The averages for these four categories, expressed in percentages of the values for the welds not stress-relieved, are given in the bottom group of Column 7, the values for the specimens not stress-relieved being 100. The following statements are based on the values in this group.

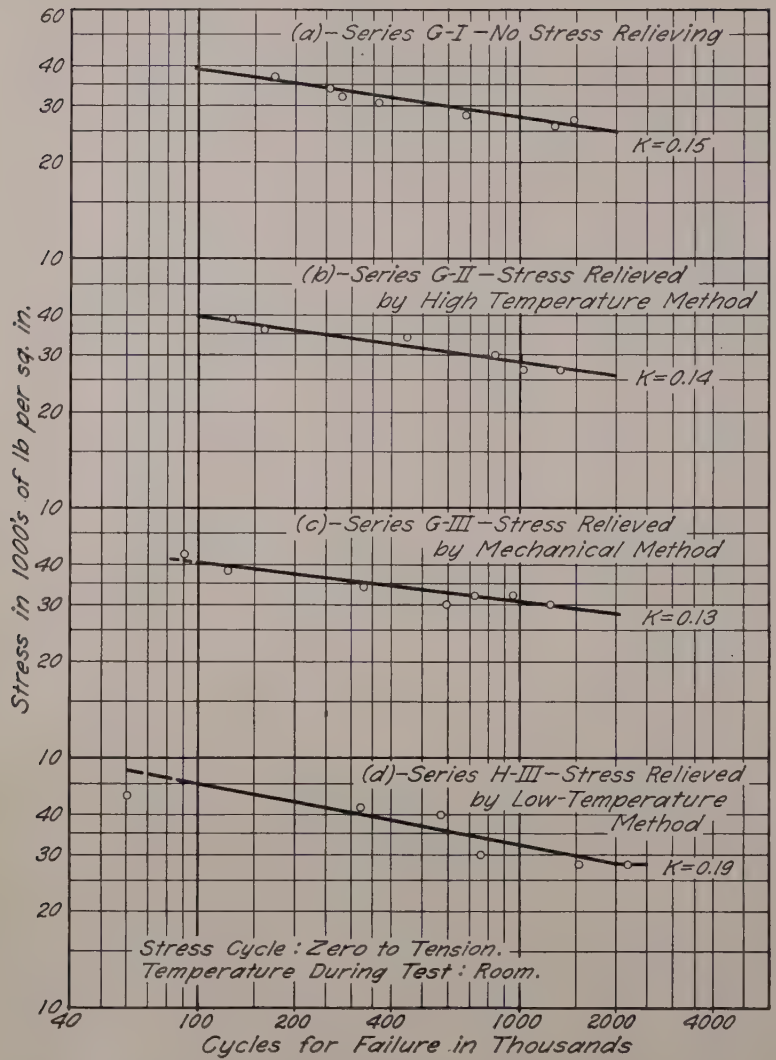
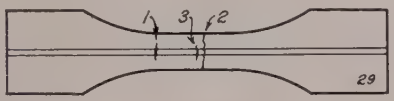


FIG. 17. *S-N* DIAGRAMS SHOWING EFFECT OF STRESS-RELIEVING ON LONGITUDINAL SINGLE-V BUTT WELDS CONNECTING ½-IN. STEEL PLATES WITH REINFORCEMENT ON (SERIES G-I, G-II, G-III, AND H-III)

Table 29

Series G-IV: Fatigue Strength of Longitudinal Butt Welds Connecting ½-in. A7 Steel Plates; Reinforcement and Mill Scale Off



Specimen No.	Maximum Tension in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength† in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
G25	32.0	754.5		25.6	3
G26	40.0	421.0	55.7	28.0	1
G27	28.0	683.2		21.9	2
G28	45.0	147.4	49.2		1
G29	30.0	495.7	43.3	21.8	3
G30	25.0	2 350.1*		25.0+	..
G31	35.0	790.8		28.3	2
Av			49.3	25.3+	

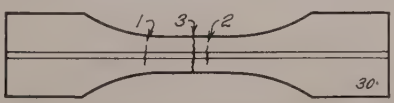
Results of Static Test—Specimen G-32

Yield Strength = 42,600 p.s.i. Red. in Area = 34%
Ultimate Strength = 63,800 p.s.i. Elong. in 4 in. = 34%
Location of Fracture: 2

* Specimen did not fail.
† Stress based on gross area of plate. $K = 0.23$ as shown in Fig. 18.

Table 30

Series G-V: Fatigue Strength of Longitudinal Butt Welds Connecting ½-in. A7 Steel Plates, Stress-Relieved by the High-Temperature Method; Reinforcement and Mill Scale Off



Specimen No.	Maximum Tension* in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength* in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
G33	40.0	527.1	49.6	33.6	1
G34	34.0	1 167.1		31.7	1
G35	47.0	118.0	48.0		2
G36	32.0	2 665.1†		32.0+	..
G37	42.9	156.8	45.5		2
G38	42.0	337.0	49.2	33.3	1
Av			48.3	32.6+	

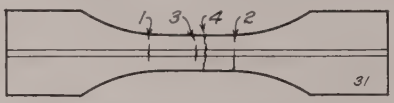
Results of Static Test—Specimen G-40

Yield Strength = 37,400 p.s.i. Red. in Area = 46%
Ultimate Strength = 59,700 p.s.i. Elong. in 4 in. = 42%
Location of Fracture: 3

* Stress based on gross area of plate. $K = 0.13$ as shown in Fig. 18.
† Specimen did not fail.

Table 31

Series G-VI: Fatigue Strength of Longitudinal Butt Welds Connecting ½-in. A7 Steel Plates, Stress-Relieved by the Mechanical Method; Reinforcement and Mill Scale Off



Specimen No.	Maximum Tension* in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength* in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
G41	32.0	1 216.7		30.2	1
G42	36.0	1 416.8		34.5	1
G44	30.0	1 938.2		29.9	2
G45	36.0	826.0		32.3	1
G46	44.2	168.9	47.0		3
G47	46.6	41.7	42.0		1
Av			44.5	31.5	

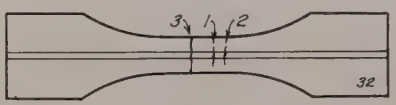
Results of Static Test—Specimen G-48

Yield Strength = 45,100 p.s.i. Red. in Area = 25%
Ultimate Strength = 66,600 p.s.i. Elong. in 4 in. = 21%
Location of Fracture: 4

* Stress based on gross area of plate. $K = 0.12$ as shown in Fig. 18.

Table 32

Series H-IV: Fatigue Strength of Longitudinal Butt Welds Connecting ½-in. A7 Steel Plates, Stress-Relieved by the Low-Temperature Method; Reinforcement Off



Specimen No.	Maximum Tension* in 1000's p.s.i.	Number of Cycles for Failure in 1000's	Fatigue Strength* in 1000's p.s.i.		Location of Fracture (See Sketch)
			$F_{100\,000}$	$F_{2\,000\,000}$	
H25	49.0	70.6	47.1		1
H26	47.0	54.6	44.0		2
H27	45.0	173.1	47.8		2
H28	33.0	1 597.5		32.1	1
H29	33.0	1 900.2		32.8	1
H30	35.0	1 227.5		33.2	3
H31	47.0	91.1	46.5		2
Av			46.3	32.7	

Results of Static Test—Specimen H-32

Yield Strength = 40,800 p.s.i. Red. in Area = 40%
Ultimate Strength = 62,700 p.s.i. Elong. in 4 in. = 36%
Location of Fracture: 3

* Stress based on gross area of plate. $K = 0.11$ as shown in Fig. 18.

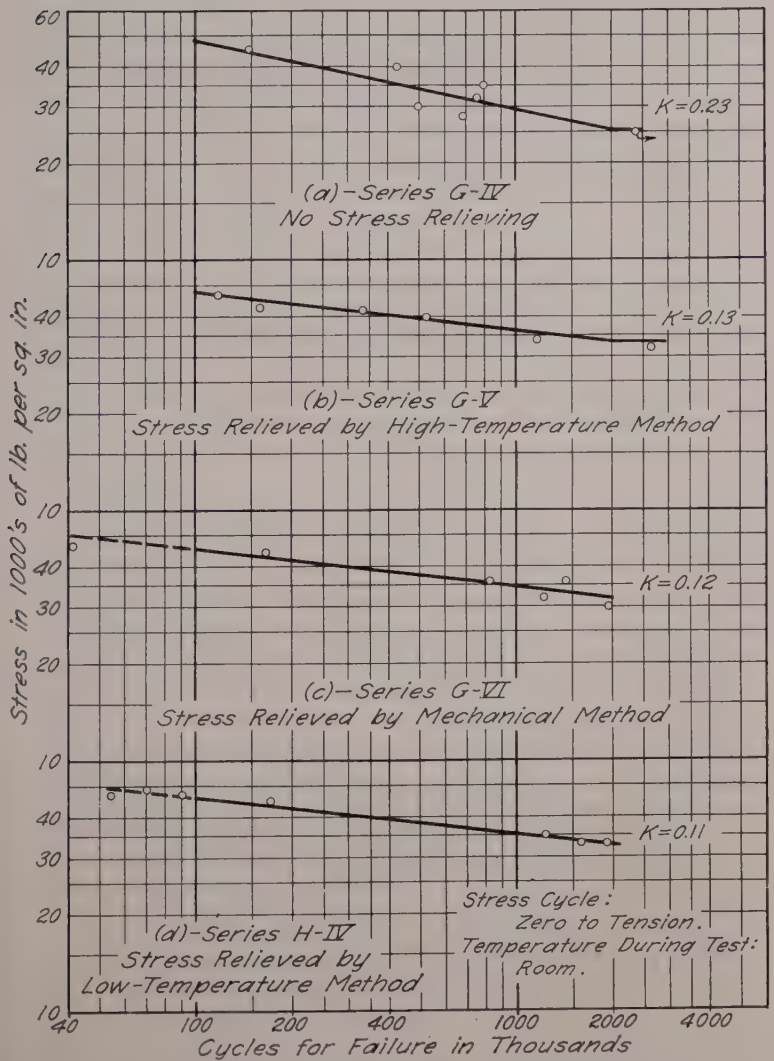


FIG. 18. *S-N* DIAGRAMS SHOWING EFFECT OF STRESS-RELIEVING ON LONGITUDINAL SINGLE-V BUTT WELDS CONNECTING ½-IN. STEEL PLATES WITH REINFORCEMENT OFF (SERIES G-IV, G-V, G-VI, AND H-IV)

Table 33

Effect of Stress-Relieving on Fatigue Strength of Longitudinal Single-V Butt Welds Connecting ½-in. A7 Steel Plates

With one exception, each fatigue value is the average of three or more tests; each static value is for one test only.

Series No.	Stress-Relieving Method	Fatigue Strength				Av of $F_{100\,000}$ and $F_{2\,000\,000}$, percent	Static Strength			
		$F_{100\,000}$		$F_{2\,000\,000}$			Yield Point		Ultimate	
		p.s.i.	%	p.s.i.	%		p.s.i.	%	p.s.i.	%
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
					Reinforcement On					
G-I	None	38 500	100.0	24 300	100.0	100.0	43 700	100.0	64 300	100.0
G-II	High-temperature	40 300	104.8	26 100	107.4	106.1	40 100	91.7	61 000	94.9
G-III	Mechanical	39 900	103.7	27 700	114.0	108.9	45 400	103.9	64 800	100.8
H-III	Low-temperature	49 900	129.6	28 200	116.0	122.8	43 000	98.4	65 500	101.9
					Reinforcement Off					
G-IV	None	49 300	100.0	25 300	100.0	100.0	42 600	100.0	63 800	100.0
G-V	High-temperature	48 300	98.0	32 600	128.8	113.4	37 400	87.8	59 700	93.7
G-VI	Mechanical	44 500	90.2	31 500	124.5	107.4	45 100	105.9	66 600	104.4
H-IV	Low-temperature	46 300	93.8	32 700	129.1	111.4	40 800	95.8	62 700	98.3
					Average, Reinforcement On and Reinforcement Off					
G-I, G-IV	None		100.0		100.0	100.0		100.0		100.0
G-II, G-V	High-temperature		101.4		118.1	109.8		89.8		94.3
G-III, G-VI	Mechanical		97.0		119.3	108.2		104.9		102.6
H-III, H-IV	Low-temperature		111.7		122.5	117.1		97.1		100.1

The average fatigue strength for the various specimens with longitudinal butt welds connecting ½-in. A7 steel plates had the following relative values: not stress-relieved, 100.0; stress-relieved by the high-temperature method, 109.8; stress-relieved by the mechanical method, 108.2; stress-relieved by the low-temperature method, 117.6. These values are averages from three[1] or more specimens with the reinforcement on and an equal number of specimens with the reinforcement off. They are also for average values of $F_{100\,000}$ and an equal number of average values of $F_{2\,000\,000}$.

The static yield point, given in the lower right-hand corner of Table 33, had the following relative values: not stress-relieved, 100.0; stress-relieved by the high-temperature method, 89.8; stress-relieved by the mechanical method, 104.9; stress-relieved by the low-temperature method, 97.1. The static ultimate strengths had the following relative values: not stress-relieved, 100.0; stress-relieved by the high-temperature method, 94.3; stress-relieved by the mechanical method, 102.6; and stress-relieved by the low-temperature method, 100.1.

The limited number of tests reported in Table 33 appear to indicate that the average values of the fatigue strengths of the butt welds connecting ½-in. A7 steel plates are generally somewhat greater for the stress-relieved specimens than for those not stress-relieved. This statement applies to specimens stress-relieved by all three methods, but the differences in the averages are somewhat greater for specimens stress-relieved by the low-temperature method than for similar specimens stress-relieved by the other methods. However, there is at least one category for each stress-relieving method for which the fatigue strength, the average of three tests, is lower for the stress-relieved specimens than it is for the specimens not stress-relieved. Further, values of the fatigue strength of welded joints manufactured as nearly as possible under the same conditions vary through a considerable range. This being true, variations in the fatigue strength of the order of 10 percent cannot be considered significant. It would seem, therefore, that the only definite conclusion which can be drawn from the data in Table 33 is that stress-relieving for the specimens reported did not in general decrease the fatigue strength but probably increased it somewhat, possibly more for the low-temperature method than for the others.

[1] In one instance, values from only two specimens were averaged.

V. Summary of Results

The tests reported in this bulletin appear to justify the following statements.

1. For $\frac{7}{8}$-in. A7 steel plates connected with $\frac{3}{16}$-in. and $\frac{1}{4}$-in. longitudinal partial-penetration butt welds in the as-welded condition and with the reinforcement on, the value of $F_{100\,000}$ was approximately 84 percent as great and the value of $F_{2\,000\,000}$ was approximately 94 percent as great as the corresponding values for similar plates without welds but with the mill scale on. However, for $\frac{7}{8}$-in. A7 steel plates with $\frac{3}{16}$-in. and $\frac{1}{4}$-in. longitudinal partial-penetration butt welds not stress-relieved but with the reinforcement off, the values of $F_{100\,000}$ and $F_{2\,000\,000}$ were very nearly the same as for similar plates without welds but with the mill scale on.

2. For $\frac{7}{8}$-in. A7 steel plates connected with transverse partial-penetration butt welds in the as-welded condition and with the reinforcement on, the value of $F_{100\,000}$ based on the transverse section of the plate was 43 percent as great for a $\frac{1}{4}$-in. partial-penetration transverse butt weld as it was for a full-penetration transverse butt weld connecting similar plates. The corresponding value for $F_{2\,000\,000}$ was 36 percent. For $\frac{3}{16}$-in. partial-penetration transverse butt welds, the corresponding values were 37 percent and 31 percent for $F_{100\,000}$ and $F_{2\,000\,000}$ respectively.

3. For $\frac{7}{8}$-in. A7 steel plates connected with $\frac{1}{4}$-in. and $\frac{3}{16}$-in. transverse partial-penetration butt welds, the *unit* fatigue strength based on the area of the fracture was increased by machining off the reinforcement. However, the effective area was reduced and the fatigue strength of the specimen as a whole was not affected by a significant amount.

4. For $\frac{7}{8}$-in. A7 steel plates connected with either $\frac{1}{4}$-in. transverse or $\frac{1}{4}$-in. longitudinal partial-penetration butt welds with the reinforcement on, a limited number of tests of geometrically identical specimens indicated that the fatigue strength was somewhat greater for those tested at -20 deg F than it was for those tested at approximately 75 deg F.

5. Values of the fatigue strength of $\frac{7}{8}$-in. A7 steel plates connected with either longitudinal or transverse partial-penetration butt welds with $\frac{3}{16}$-in. and $\frac{1}{4}$-in. nominal penetration are summarized in Table 11, p. 26.

6. For $\frac{1}{2}$-in. A7 steel plates connected with transverse single-V butt welds with the reinforcement and mill scale off:

   a. The fatigue strength was only slightly increased by relieving the stress by the high-temperature method.

b. There was no significant difference between the fatigue strengths of specimens welded with E6010 electrodes and those welded with E6012 electrodes.

7. The limited number of tests reported in Table 33 appear to indicate that the average values of the fatigue strength of the butt welds connecting ½-in. A7 steel plates are generally somewhat greater for the stress-relieved specimens than for the specimens not stress-relieved. This statement applies to specimens stress-relieved by all three methods, but the differences in the averages are somewhat greater for specimens stress-relieved by the low-temperature method than for similar specimens stress-relieved by the other methods. However, there is at least one category for each stress-relieving method for which the fatigue strength, the average of three tests, is lower for the stress-relieved specimens than it is for the specimens not stress-relieved. Further, values of the fatigue strength of welded joints manufactured as nearly as possible under the same conditions vary through a considerable range. This being true, variations in the fatigue strength of the order of 10 percent cannot be considered significant. It would seem, therefore, that the only definite conclusion which can be drawn from the data in Table 33 is that stress-relieving for the specimens reported did not in general decrease the fatigue strength but probably increased it somewhat, possibly more for the low-temperature method than for the others.

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